A MANUAL

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A MANUAL

OF

FOREST ENGINEERING FOR INDIA

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ROG/M

BY

CHARLES GILBERT ROGERS,

FELLOW OF COOPER'S HILL, DEPUTY CONSERVATOR OF
FORESTS, IMPERIAL FOREST SERVICE OF INDIA.

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Part III.—ROAD-MAKING.

SECTION I.—THE DIFFERENT KINDS OF ROADS.

§ 1. The more important products of a forest are in the majority of cases bulky, and the cost of transporting them to the place of sale or of use affects their value in the forest very considerably—so much so, that in the less accessible portions of forests the mere extra cost of transport of the produce often renders its sale unremunerative. The cost of extraction of forest produce is frequently greater than the actual value of that produce in the forest. Where transport by water is not possible, forest produce must be taken out along roads, down specially prepared troughs or slides, or over inclined wire-rope ways. The roads may be constructed for ordinary traffic, such as carts and laden animals; or may be specially prepared for transport of the forest produce, as in the case of sledge-roads, tramways or rolling-roads.

Ordinary roads or paths are much more useful for ordinary administrative purposes than the specially prepared roads referred to above.

The value of a forest is greatly enhanced by ease of access, and the consequent reduction in cost of transport of the produce.

§ 2. Roads may be classed as—

(1) Temporary roads.
(2) Permanent roads.

Temporary roads are usually constructed to meet a temporary want, and need only be sufficiently durable for the purpose for which they are constructed. Temporary roads are commonly made, under forest management, to facilitate the export of forest produce. Where no roads exist forest produce is often unsaleable.

The existence of temporary roads will increase the price offered for the forest produce, and purchasers of forest produce may reasonably be compelled to use them for the extraction of forest produce, and not be allowed to take their carts indiscriminately through all parts of the forest; if these roads are systematically and carefully laid out, such a procedure will cause but little inconvenience to the purchaser, and will preserve to a great extent the young crop of seedlings and poles which are already on the ground, ready to take the place of the trees which are being removed. The position and gradient of temporary roads should be carefully chosen to prevent their becoming water-courses in the rainy season in those parts of India where the rainfall is heavy. In laying out temporary, and for the matter of that any, roads we should remember that if all the loaded carts move in one direction *only*, steep ascents in that direction must be avoided, since full carts can go down much steeper gradients than they can come up. The actual gradients permissible depend upon the load and the nature of the carts used. The limit of steepness should be fixed so that the loaded cart should be completely under control when moving down the steepest inclines, while the empty carts can be easily drawn up them.

Temporary roads are usually laid out winding, in order to obtain a suitable gradient, so as to avoid excavation as much as possible in opening up the forest, and to reduce to a minimum the number of valuable trees sacrificed in order to make the road. Temporary roads should be constructed as cheaply as possible, so long as they are passable to the class of traffic for which they are made; they should be metalled only where absolutely necessary.

When temporary roads cross streams whose beds are dry for the greater part of the year, and only occasionally contain water, inclined tracks are dug in the banks to allow loaded carts to travel up and down easily; and a track across the bed of the stream itself should be made passable for carts at the beginning of the season in which the forests are worked.

§ 3. *Permanent roads* are maintained in good order throughout the working season, or in some cases throughout the whole year.

The direction of permanent roads must be determined with much care and precision, in order to ensure the selection of the best available routes which the nature of the country passed over will permit of. Permanent roads should be made as short as possible consistent with a good gradient and a moderate cost; shallow excavations should be made in order to obtain a more direct line, but heavy rock cuttings should be avoided as far as possible. Bridges should be constructed only when absolutely necessary, as they will require continual repairs if constructed of wood, and will be expensive to make if built of masonry or brick-work. Bridges are required to carry the roadway across deep rivers; and culverts must be built beneath and through embankments made across depressions down which the natural drainage of the country flows.

Greater care must be paid to the efficient drainage of permanent roads than of temporary ones, especially as regards transverse surface and under drainage.

As a general rule the drier the surface of the road is kept the easier will be the traction over it, the less will be the wear and tear on it. After a long period of drought, however, the surface of an unmetalled road becomes brittle, and is easily cut up.

Permanent roads should be passable to traffic at all times of the year, and in localities where the rainfall is heavy must, in consequence, be covered with a layer of gravel, or, if practicable, with a layer of broken stone properly consolidated (*metalled*), (see § 25, page 21 *et seq.*).

Forest roads in the plains of India are generally used for the extraction of forest produce in the dry season of the year only, and in consequence are rarely metalled. If the traffic is so heavy that the surface of the road becomes cut up, the road should be covered with a layer of gravel, and if this does not afford sufficient protection, it must be metalled.

§ 4. *Fair-weather roads* are only passable to carts during the cold weather or working season; they are not open to traffic during the rainy season. They are nearly always cart-roads. They are made by clearing the ground of trees and rank vegetation only, and are further improved by making ditches on either side to drain the roadway. The earth dug out from the ditches is utilized in raising the central portion of the road, and thus allowing the rain which falls on it to run off quickly. The trees which are on the track should be dug up by the roots.

Fair weather roads are only found in the plains of India or in flat parts of the country. They cannot be made in the hills.

§ 5. Roads may be classed according to their gradients and the nature of traffic passing over them into—

(1) Cart-roads.

(2) Bridle-paths—

 (*a*) For laden camels, mules, ponies or cattle.

 (*b*) For riding only.

(3) Inspection paths.

§ 6. *Cart-roads* are roads constructed for the passage of carts and other wheeled vehicles; they vary in width from 12 to 30 feet, according to the nature and intensity of the traffic which passes over them. They should be made as nearly level as circumstances will permit; the gradients given to them should be very low, but may vary between limits which are fixed by the nature of the ground to be traversed and the character of the vehicles used. The larger the carts the lower should be the gradient of the road. Where small carts are used, or the traffic confined to one direction only, the gradient may be steeper. Draught animals can haul the greatest possible load on smooth, perfectly level roads, but it is not practicable to make a perfectly level road for any considerable distance except in the plains. It has been found by experiment that the weight which draught animals can draw up slight inclines of no great length is not materially less than that which can be hauled along the level.

On a road which rises 1 foot vertical in 44 feet horizontal a horse can draw ¾ of the load drawn on the level; if the gradient be increased to 1 in 24 he can draw ½ that load;

while on a road which rises 1 foot in 10 feet he can only draw ¼ of the load drawn on the level. A slight gradient is often intentionally given to roads to facilitate the drainage of their surfaces.

The traffic capacity of a road depends partly upon its steepest gradient, as that determines the maximum load hauled without additional help at the steep inclines, a practice to be avoided. A few steep inclines of considerable length will consequently materially lessen the load hauled, and this will cause a waste of power on the more level portions.

Bullocks or buffaloes are the draft animals universally used in India, and these, unlike horses, are not capable of exerting a greater power for a short time, so as to draw a load up short steep inclines.

Cart-roads in the plains of India are usually nearly level or have very slight gradients; they are sometimes raised above the general level of the country in order to prevent the interruption of traffic during the occurrence of extensive floods.

In the hills cart-roads may have more or less steep inclines; the gradient should be as low as practicable, and all unnecessary ascents and descents should be carefully avoided.

§ 7. In Europe, experience has shown that it is cheaper to construct tramways (see Vol. III., Part V., Section V.) in the hills for the extraction of forest produce than to make cart-roads, which must be metalled in order to stand the rush of rain-water down them. The tramways laid down are usually portable, and can be moved from place to place if necessary. A tramway can be laid on a much narrower track than that which is necessary for a cart-road, so that it is much cheaper to make in the first instance and costs less to maintain in good order.

The ruling gradient of tramways, both as regards up and down gradient, is less than that of cart-roads. The cost of extraction of forest produce along tramways is less than along cart-roads.

§ 8. *Dragging roads.*—In localities in the plains of India where there are no cart-roads, timber and bamboos are often extracted by buffaloes and bullocks along dragging roads.

These roads can have gradients intermediate between those allowed on cart-roads and bridle-paths.

The roads are soon cut up by the timber and bamboos dragged over them, and in localities where the rainfall is heavy soon degenerate into ravines.

Where there are no cart-roads, dragging must often be allowed in order to render the extraction of forest produce possible; but as soon as cart-roads have been laid out no dragging should be allowed in localities where the tracks used for this purpose are liable to degenerate into ravines.

§ 9. *Camel roads.*—Roads constructed for the transport of forest produce by camels may have steeper gradients than those allowed on cart-roads, though not so steep as those permitted on bridle-paths for mules, ponies and cattle. The width of the road depends on the nature of the load transported, and should be greater when the road follows the side of a hill than when on the flat. For further information on the subject of camel roads, see Vol. III., Part V., Section II.

§ 10. *Bridle-paths for laden animals* are usually confined to hilly districts where it is too expensive to construct cart-roads. The gradients of such bridle-paths may be steeper, and their width less, than for cart-roads. The width of bridle-paths varies as a rule from 6 to 8 feet. Bridle-paths are therefore cheaper, being narrower and shorter, than cart-roads.

Bridle-paths for riding animals are practically inspection paths having gradients not too steep for the passage of a ridden horse, but too steep for that of a laden animal. The gradient must not be excessively steep where rainfall is heavy, as the surface may be seriously damaged during the rainy season, and the repairs will be more costly.

Where practicable, gradients suitable for pack animals should be given to a riding-path with a view to its utilization as a route of export when necessary. All unnecessary ascents and descents should be avoided. It is not advisable to make the gradient of any road absolutely uniform for long distances; slight changes in the gradient are preferable: an easy gradient is a relief from fatigue to a draught animal. The route and gradients of bridle-paths should be carefully chosen to give directness and comparative ease of traction.

§ 11. *Inspection paths* are constructed to facilitate the thorough inspection of forests. They are especially necessary in hill forests, where the proper inspection of the interior is a difficult task unless aided by such paths. They need be only 2 to 4 feet wide to allow of foot passengers walking along them. All trees and branches should be cleared for 2 feet on either side of the path itself. While laying out inspection paths we should remember that they will be much more useful if passable to a pony, and that they may be subsequently improved into paths suitable for riding or pack animals, and in some cases even into cart-roads, as the forest becomes opened up; and that the gradients given to them should be as gentle as the circumstances of the case will permit, consistent with a thorough inspection of the forest.

Inspection paths should be laid out according to well-matured plans with a view to opening up the forest as completely as possible at the least cost practicable; and thus a considerable saving may be effected when the working of the forest becomes more intense. The purchasers removing loads of dry sticks, grass, seeds, and other minor produce will make use of inspection paths, and accessibility promotes demand for forest products.

Inspection paths are always useful for the efficient protection of the forest from fire, and this point should not be forgotten when they are being laid out.

SECTION II.—SHAPE OF ROAD SURFACE: ITS DRAINAGE; RETAINING WALLS; SYSTEM OF METALLING ROADS; REPAIRS TO ROADS.

§ 12. **Transverse Profile of the Road.**—As far as possible water should never be allowed to rest on the surface of a road, as it makes the road surface soft and more liable to be cut up by the traffic which passes over it. The centre of all roads and paths more than 6 feet wide should be higher than the sides. This raising of the road is called the *camber* or *barrelling* of the road.

The camber given to metalled roads is much smaller than that required on unmetalled roads. Codrington[1] says for a road 18 to 20 feet wide a camber of 3 or 4 inches is enough. It is a mistake to round the road surface too much.

In the hills the surface of roads or paths less than 6 feet wide may have a transverse slope either inwards or outwards. The transverse slope given to cart-roads should be 1 in 24; if the slope is made too steep water running off the road will cut up its surface, while if the slope is too low the water will remain on the road, sinking into, softening, and causing it to wear out more rapidly.

Figures 1 and 2 show two common forms for the surface of roads *in the plains:*

FIG. 1.

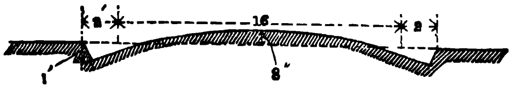
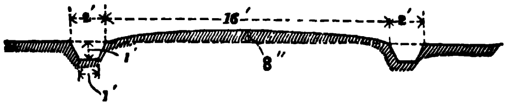


FIG. 2.



Figures 1 and 2 are cross sections showing the common forms of forest cart-roads in the plains of India. Scale 8 feet = 1 inch.

The trussed straight edge shown in Figure 29, page 84, can be adopted to setting out the transverse profiles of the roads shown in Figures 1 and 2.

The dimension of the ditches which are usually constructed on either side of the road to take off the surface drainage depends upon the rainfall of the locality. In the case of unmetalled roads they will be found sufficiently large if they are designed so that the earth which is dug out of them is sufficient to give the road the camber which it requires.

---

[1] "The Maintenance of Macadamised Roads," by T. Codrington.

The slope which should be given to the sides of the ditches depends upon the angle of repose (see page 81, § 71,) of the soil in which the road is being made.

When *fair-weather* roads are made *in the plains*, the earth taken out of the ditches is placed on the road to raise its centre. The condition of the road surface depends mainly upon the way in which the earth is placed; it should be first thrown on to the central portion of the road until that portion is raised to the required height above the sides, then the remainder of the earth, if there is any, should be spread evenly to the correct transverse profile of the road. Both ditches should be dug at the same time, and the earth coming out of the ditches should be spread over the portion of the road lying between them. The depth and width of the ditches depend upon the width of the road; for a road 16 feet wide, ditches 2 feet wide at the top and 1 foot at the bottom and 12 inches deep, will yield sufficient material to give the proper shape to the road surface. The sides of the ditches are sloped to prevent the falling of the earth. The bottom of the ditches should have a fairly uniform slope in the longitudinal direction.

When the road slopes for a considerable distance in one direction, the water which falls on the road surface accumulates in the side drains, and is apt to erode them considerably as soon as its volume becomes large. In order to prevent this erosion, the side drains should be interrupted at intervals, and channels made on either side of the road leading away from it down which the water can be carried off and allowed to escape without doing any harm.

The distance between these side channels depends upon the gradient of the road and the character of the rainfall. No precise rules can be given on this subject, and the position and number of side cuts must be determined on the ground when making the road.

A road running transversely to the slope of a hill-side may have part of its width in cutting and part on embankment, but this plan should be adopted only on gentle slopes or where the material for the construction of the embankment is very stable. On a steep hill-side, or where the soil is of a loose and unstable nature, it will be necessary to construct retaining walls to hold up the made portion of the road. It will often be found cheaper to cut the whole width of the road out of the hill-side, throwing the material from the cutting down into the ravine below, than to construct retaining walls to support the made earth.

In every case the part of the road which consists of made earth will *settle* (see § 75, page 87,) more than the other part of the road, and must be either made higher to allow for this in the first instance, or else raised to the proper height after the settling process is complete.

§ 13. Opinions differ considerably as to the transverse profile to be given to hill-roads 6 feet wide, or less; some advocate a slope from the outside to the inside, and others exactly the reverse; the object in the first case is to prevent the surface water from damaging the outer edge of the road, and in the second case to obviate the necessity for a drain along the inner edge of the road and the accumulation of water in it and the provision of substantial transverse under drains. In either case, where the gradient is steep, surface cross drains should be formed at frequent intervals, to carry the surface water off the road, preventing its accumulation and obviating the risk of the road surface being washed away. The advantages of having an inward slope are—

(1) The protection of the outer edge from damage by the surface drainage. If the road slopes outwards, numerous revetment walls will often be necessary.

(2) The greater protection afforded to traffic going round corners.

(3) That the drainage of the hill above does not flow across the surface of the road, but is taken under it. Open cross drains require constant attention or they are worse than useless.

(4) That fewer cross drains will be required on the surface of the road where the gradient is steep.

(5) That the greater portion of the traffic will pass along the inner side of the path, *i.e.*, the solid portion. In the hills, men always walk on the lowest part of the path; with an outward slope this means the outer edge where the path is weakest.

The advantages of giving a hill path an outward slope are—

(1) That there is less danger of the road slipping away by reason of its own weight along the outer edge.

(2) That there is no danger of the inner ditch being filled up by slips, and the surface of the road being destroyed by the stream of water which would in consequence run down it.

(3) That fewer cross drains are required where the road is level.

(4) That the expense of the inner ditch and the culverts which it necessitates is obviated.

If it is decided to give the path an inward slope in the transverse direction, that slope should be 1 in 18. If the annual rainfall is under 20 inches, an outward slope should be given to the path, as there cannot be much wash to cut up its surface, and the cost of making the road will be much decreased. The path should in any case be given an outward slope until the inner drains have been constructed and the made earth has settled. On bare hill-sides the road surface should generally slope inwards, especially if the soil is unstable.

The cost of constructing a road with an inward slope and a good paved drain is considerably more than one which has no inner drain and a general outward slope.

On the Ranikhet Road, where the outer retaining walls are more than 6 feet high, the road surface slopes outward, otherwise it has a general inward slope.

§ 14. DRAINAGE OF ROADS.—Slips of earth, both in cuttings and embankments, may often be traced to insufficient drainage. A road surface not kept dry, and having a considerable traffic passing over it, will require very considerable repairs annually; the drier the surface of the road is kept the less will be the wear and tear on it. An efficient system of drainage must be provided, and precautions taken to ensure that the drains are always clear, and are interrupted where necessary.

We have not only to provide for the rain which falls directly on the surface of the road, but for that which falls on the slopes above the road, and also for the passage of the natural drainage of the country through the road.

When an unmetalled cart-road is made with a fairly steep gradient the side ditches should be interrupted at intervals, and the water which is collected in them led off on either side of the road by short drains. If the side drains are continuous, the volume of the water which is caught by them will increase with the length of the road, and will either erode the bottom or sides of the drain, or, if the drain becomes choked, will flow down and tear up the surface of the road. The steeper the gradient of the road, the more frequent should be these interruptions.

§ 15. *Streams* which contain water all the year round should be bridged or made fordable. The different kinds of bridges, suitable for forest requirements, which may be constructed, and the principles upon which their construction is based, is considered fully in Part IV. of this Manual, page 109 *et seq.*

Beds of streams that are dry, except during the rainy season and are nearly on the same level as the road, may be left unaltered, the road across them being made passable as soon as the rainy season is over.

§ 16. Small quantities of water may be taken either over the road by means of an *Irish bridge,* or under the road in a culvert. An *Irish bridge,* or paved ford, is practically a pavement of stones or bricks over which the water flows, and is used only where the water level is but little below that of the surface of the road itself. Figure 3 shows a cross section through an Irish bridge. The section is longitudinal so far as the road is concerned.

FIG. 3.

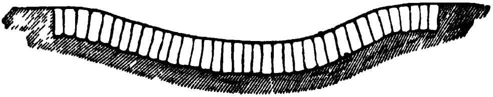


Figure 3 is a cross section of an Irish bridge for carrying a small stream over a path or road.

In constructing Irish bridges the stones or bricks should be placed on their ends; and if bricks or boulders are used mortar should be added. Stones, more or less squared, 12 to 18 inches long, 6 to 9 inches deep, and 4 to 6 inches broad, should be used if procurable.

Special care must be taken not to have the side slopes of the Irish bridge too steep; if the slopes are long and gradual, and the Irish bridge wide, the trough will carry the same amount of water as if the slopes are short and steep and the passage narrow. If the side slopes are gentle, carts will be able to cross the Irish bridges easily, and there will be no chance of their sticking in them. The slope should in no case exceed the maximum gradient for the class of road which is being made.

§ 17. If a small water channel crosses a road it may be taken under the road without raising its surface in a syphon, as shown in Figure 4.

FIG. 4.

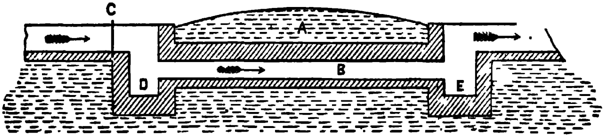


Figure 4 is a longitudinal section of a masonry syphon under a road. The shaded portions are masonry in section. A *is the roadway;* B *the channel through which the water flows;* C *grating to prevent the entry of rubbish into the syphon;* D *and* E *are wells constructed to receive the silt carried down by the water. The arrows indicate the direction in which the water flows. Scale 8 feet = 1 inch.*

As the syphon is liable to get blocked with rubbish, an iron grating should be placed at the higher or upper end so as to keep out rubbish, and even then finer particles will find their way into the well. Where the amount of water to be passed through is very small, wooden slab drains, square in section, or earthenware pipes, may be used.

§ 18. Culverts may be used for the passage of small quantities of water when the stream or drainage channel is considerably lower than the surface of the road. Culverts may be constructed of bricks or stone, and should be set in mortar if the weight of earth above them is considerable. The size and method of construction of culverts will be discussed in Part IV., Section VII., page 230 *et seq.*

In the Sonthal Pargannahs the water of rivulets, or that which would collect in depressions on the higher ground in time of heavy rain, is allowed to pass through the embankment by constructing the lower part of it of boulders, so arranged that the water can easily percolate through it: the boulders on the outside of the higher side of the embankment are placed fairly close together, so as to keep out silt and floating rubbish as much as possible. (*F. B. Manson.*)

§ 19. The side drains of a road in a cutting should be protected from obstruction due to the falling of earth into them from the slopes; if the drain becomes blocked the pent-up water may flow down the road and damage its surface. Open or covered side drains should be made from 6 inches to 2 feet deep and 2 to 4 feet wide, to receive the water which falls on the slopes and to carry it off to the end of the cutting. These drains should not come within 6 to 12 inches of the bottom of the slope (see Fig. 5), to prevent their being blocked up by small falls of earth. Covered side drains may be in brick or stonework, dry or cemented; or may be pipes of 6 inches diameter and upwards. The drains are covered with coarse grass, reeds, brushwood, etc., and then with coarse loose gravel or broken stone.

FIG. 5.

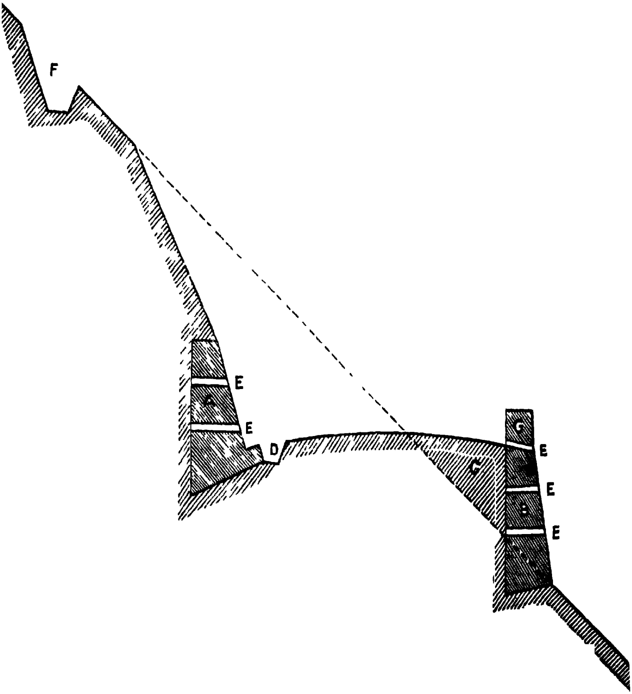


Figure 5 is a cross section of a road partly in cutting and partly in embankment on sidelong sloping ground. A *is a breast wall to support the foot of the slope;* B *is a retaining wall to keep the made earth* C *from slipping down;* D *is the drain on the inside of the road;* E, E *are weep holes, 4 inches square, to allow the water which collects in the made earth to escape;* F *is the water-tight catch-water drain;* G *is the parapet wall for the protection of the traffic. The dotted line shows the original surface of the ground. Scale 8 feet = 1 inch.*

A *catch-water drain* is often necessary when the ground is unstable. It is dug on the slope above the cutting, and about 6 feet from its upper edge, to intercept the surface water which falls on the slope, and to prevent its soaking into the upper part of the cutting, and causing an earth-slip. Such a drain is shown at F in Fig. 5. Where the cuttng is deep and the soil unstable a second catch-water drain may be constructed half-way up the slope.

A catch-water drain may also be made in the natural slope above the foot of an embankment deposited on sidelong ground, to prevent the surface drainage from soaking into the base of the embankment and so affecting its stability.

§ 20. DRAINAGE OF HILL ROADS AND PATHS.—The system of draining cart-roads in the hills is similar to that adopted for roads in the plains.

The side drains catch the water which falls on the surface of the road. This water is led under the road in culverts, or over the road on Irish bridges. Sometimes where streams cross the road both a culvert and Irish bridge may be constructed at the same place; the culvert takes off the ordinary flow of water, but when the stream is in flood, the water flows over the Irish bridge as well as through the culvert. Bridges are constructed across the larger streams,

Water flowing down a side drain having a steep slope will scour away its bed, unless it be lined or stepped with stone block paving, or slabs of wood fixed at frequent intervals across the ditch to check the rush of water. The water should not be allowed to remain in a ditch on the inner side of the road, but should be carried off at frequent intervals by masonry-lined holes (sometimes called scuppers) communicating with the transverse culverts or under drains.

Water allowed to remain in the inner side drain may percolate beneath the roadway, and endanger the stability of the outside retaining wall.

In the case of bridle or inspection paths, where no inner drain is constructed, and the surface of the road has a slight outward slope, surface drains running obliquely across should be constructed to take off the surface water. These obliquely arranged surface drains may be constructed of poles embedded lengthwise in the road and projecting about 3 inches above it, or else of a line of stone blocks. The path is sloped gradually to the cross drains, and the poles or stone blocks should be strengthened with earth backing, as shown in Fig. 6.

FIG. 6.

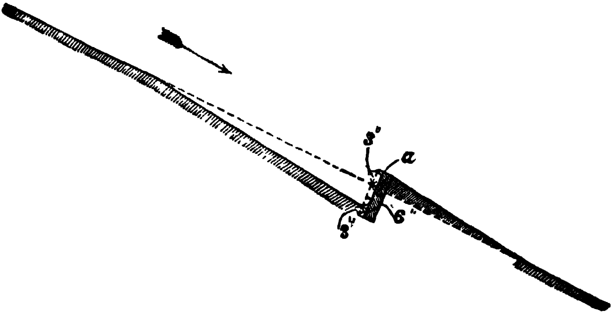


Figure 6 is a cross section of an open surface drain, made obliquely across a bridle-path with an outward slope, to take off the surface drainage. The dotted line shows the surface of the road before the drain was constructed. **A** *is the stone or wooden lining of the drain seen in section.*

These obliquely arranged drains will soon become choked and useless if the path above is not cut down to a gentle slope.

The outer end of the drain should have a lip made of a flat stone to prevent the edge of the path from being washed away.

The distance between these cross drains depends upon the gradient of the path and on the rainfall; the steeper the gradient, the closer together should be the cross drains.

Oblique surface drains should also be made when the surface of the path slopes inwards, and in this case the water which falls on the surface of the path is led into the inner side drain. These obliquely arranged surface drains should be constructed as soon as the longitudinal slope of the path exceeds the transverse slope which has been given to it.

§ 21. RETAINING WALLS.—When a hill-road or path is formed partly by cutting into the hill-side and partly of the earth obtained from the cutting (see Fig. 5, page 15), it is often necessary to construct a wall along the outer side of the road to retain the earth of which the outer portion of the road is made, and to prevent it from slipping down or being washed away by heavy rains. These walls are known as *revetment* or *retaining walls.*

They are necessary where the slope of the hill-side is steeper than the natural slope of the material (see page 81, § 71,) of which the made portion of the road is constructed, unless the whole road is cut out of the hill-side. Retaining walls are usually made of dry rubble masonry. Retaining walls should be avoided as far as possible in localities where skilled labour is difficult to obtain, on account of the expense which would be incurred in constructing them. In such places it will probably be found cheaper to cut the whole width of the road out of the hill-side, unless the latter consists of hard rock.

A parapet of dry rubble masonry is often built on the top of a revetment wall for the protection of traffic.

The rules for the construction of retaining walls in force in the Public Works Department, Panjab, are as follows[1]:—The face batter is to be 1 in 4 for any height up to 14 feet. For higher walls it can be 1 in 3 for the part below 14 feet if thought necessary. In addition to the face batter, all retaining walls to have an offset at the back of 3 inches, at heights of 8 feet, 14 feet, and 18 feet from the top of the wall. The back of the wall up to a height of 14 feet to be vertical. The width at the top of all walls is to be 2 feet. All stones are to be laid with their beds at right angles to the face of the wall. In walls exceeding 18 feet in height, the back of the wall below 18 feet from the top may (if the soil permits) be parallel with the face, so as not to exceed 7 feet in thickness. In walling exceeding 20 feet in height, bands of stone set in lime mortar, 2 feet high, should be inserted at intervals.

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[1] Colonel J. W. Thurburn, R.E., Superintending Engineer.

A bevel plumb rule (see Fig. 28, page 82,) should be used in order to ensure the correct slope being given to the outer face of the wall. The inner face of the wall is usually made vertical. The bed joints of the wall should be perpendicular to the outer sloping face. The base of a retaining wall is always wider, sometimes very much wider, than the top.

When retaining walls are built of rubble masonry (with lime mortar) the outer face may be made vertical.

Retaining walls should be built of large stones, and great attention must be paid to the bond, especially that through the thickness of the wall. Small holes, technically called *weep-holes*, should be left at intervals through the entire thickness of the wall to allow the water which sinks into the made earth to flow away. These holes should be about 4 inches square; they should be placed about 3 feet apart horizontally and 2 feet vertically, and should be arranged chequerwise, not vertically one under the other. These drainage holes are more necessary in retaining walls constructed of masonry than those which are made of dry rubble; as, if no means of escape for the water which sinks into the made portion of the road be provided, it will accumulate behind the wall, and may cause it to bulge or fall.

Retaining walls must have firm foundations dug out of the original slope of the *hill-side* itself. If the wall has to support considerable weight, the foundations must rest on solid rock, if this is not far below the surface. Where the foundation is not on rock, a foundation trench not less than 2 feet deep should be dug, and the foundation bed consolidated by ramming if necessary.

Figure 7 is a section across a bridle-path showing a retaining wall.

FIG. 7

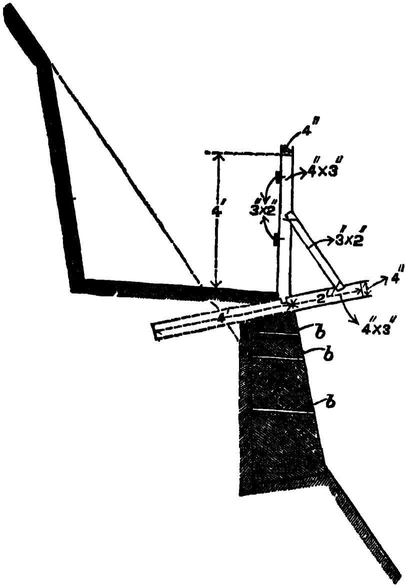


Figure 7 is a cross section of a bridle-path showing the construction of a retaining wall and also of a good form of wooden railing for the protection of the traffic. a *is the retaining wall;* b, b *weep-wholes in it. The dotted line shows the original surface of the ground. Scale*$=\frac{1}{80}$.

Where a bevel plumb rule is not used it is advisable to mark the position and sectional profile of retaining walls *in situ* by means of sticks or bamboos and string. This ensures correctness of shape and size and length.

§ 22. **BREAST WALLS** are constructed in the same way as retaining walls, but are used to support the foot of the slopes of cuttings as is shown in Fig. 5, page 15, in order to reduce the amount of cutting that would be necessary to get a given width of road, when the angle of repose (see § 71, page 81,) of the soil in which the road is being made is very small. They should be built directly the earth-work is finished. Their height should be such as will reduce the slope of the cutting in the hill-side above to its natural angle of repose. The back of the breast wall should be vertical for dry rubble masonry ; the front may be given a batter of 1 in 3.

§ 23. RAILINGS.—When a bridle-path or road is made across very steep ground, it is necessary to construct a railing or parapet wall along its outer edge to protect the traffic and to give security to travellers. A parapet wall of dry rubble may be made along the outer edge of a cart-road, but a wooden railing is better for a bridle-path, as it takes up very much less room and is cheaper to make where wood is available.

The construction of a simple and strong form of railing in use in the Jaunsar Forest Division, North-Western Provinces, is shown in Fig. 7, page 20. The whole of the wood-work is tarred with a vegetable tar extracted from the chir pine (*Pinus longifolia*), in order to add to its durability.

§ 24. WHEEL-GUARDS.—Wheel-guards are necessary on hill cart-roads to prevent carts knocking down the dry rubble parapets of the bridges, or damaging the inner drain of the road, especially on curves. The wheels of carelessly guided carts often go into the side drains and displace the side facing-stones, causing the drain to be blocked up and made useless for carrying off the surface water. In order to protect the side drains and bridge parapets, stout posts 4 feet long and 8 inches in diameter, buried 1½ feet in the ground, should be placed at the corners and angles of the bridge parapets, and at intervals of 15 to 40 feet along the inner drain around curves.

§ 25. METALLING ROADS.—The surface of a road may be made harder and more durable by depositing on it a layer of gravel or broken stone thoroughly consolidated. The road is then termed a *metalled road*, and the material used *road-metal*. By metalling a road the friction is diminished, the weight hauled with a given power is increased, and the road surface is made more durable. It has been estimated that the weight which can be drawn on a good macadamised road is three times and on a kankar road in proper repair, four times that which can be drawn on an unmetalled road with the same power.

The vehicles used on a metalled road do not require repairs so often as those on unmetalled roads. The layer of metal also acts as a partially water-proof covering to the road bed.

The surface of the metalling should be smooth, hard compact, and well consolidated. The layer must be supported by an unyielding road bed surface. A metalled road can be used all the year through; an unmetalled road is unfit for heavy traffic during the rainy season.

§ 26. Suitable gravel for metalling may be obtained from the beds of the streams which cross the road, or from any decomposing rock which may exist on or near the road. The cost of spreading gravel over a road in the neighbourhood of a stream will be small. The gravel should be passed through a screen or large-meshed sieve to separate the larger stones from the smaller ones; the larger stones may be deposited on the earthen surface and rammed into it, and the smaller gravel, etc., used for the surface of the layer of metalling.

Rounded water-worn stones, shingle from a sea beach, and similar material must be mixed with a binding material (sand) to ensure their consolidation in the road crust.

A layer of gravel 6 to 8 inches deep will be sufficient for most forest cart-roads: half this depth may be put down in one year and the remainder the year following. The layer of gravel should be consolidated by rolling, or by ramming if no rollers are available, when it is slightly moist.

The gravel should be put down just before the rains, if labour can then be obtained, so that it may become consolidated before the next export season commences.

Purchasers should not be allowed to drag timber, bamboos, and other forest produce over any road.

As soon as ruts begin to form they should be filled by raking gravel from the nearest portion of the road into the rut.

This process should be repeated as required until the gravelled surface ceases to yield to the weight of carts passing over it. If this precaution be neglected, the layer of gravel will soon be broken through, and the road surface will be almost as bad as if it had never been covered with gravel at all. A few men should be permanently on this work.

§ 27. In some places in Assam, owing to the swampy nature of the ground, it is often impossible to construct a road in the ordinary way fit for elephants to pass over, and the following system of *corduroying* has been introduced by Mr. D. P. Copeland, Deputy Conservator of Forests, with great success. Rough logs 2 feet and more in diameter are placed transversely across the line of road at intervals of from 2 to 6 feet. These logs extend about 2 feet beyond the intended width of the road on either side; after the logs have been placed in position, they are adzed down (3 or 4 inches) along the width of the roadway. The 2 feet on either side of the road being left untouched, a notch 3 or 4 inches deep is thus made in each log, the exact width of the road. Long logs, fitted close together, breaking joint with each other, are then laid in the notches, the length of the logs being parallel to the direction of the road; and across these again, parallel to the notched logs first laid down, a good layer of reeds is laid the full width of the roadway and covered with 6 inches of earth. In order to prevent the earth from being pushed off by the traffic, young saplings or bundles of reeds are tied along both sides of the roadway. If Uriam (*Bischoffia javanica*) logs are used, and necessary repairs attended to for a couple of years, a permanent roadway is formed which can be treated in the ordinary way.

§ 28. The two systems of metalling roads generally adopted are those introduced by Macadam and Telford; a road metalled according to Macadam's system is termed *macadamised.*

Macadam's System.—The stone for metalling is broken into small pieces approximately cubical in shape, the maximum length of the side of the cube being about 1½ inches; the tougher the stone the smaller it may be broken, the smaller the pieces of stone the sooner will they be consolidated to form a hard surface to the road. The usual method of testing the size of road metal is to pass it through a ring of sufficient diameter to allow the largest size of stone permitted to pass *all ways* through it. In breaking up rock to form road metal, only 50 to 60 per cent. by volume of the rock will be available for road metal to a 2-inch gauge.

The total thickness of metalling varies from 6 to 12 inches consolidated to 5 and 10 inches respectively; the thickness of the layer depends upon the hardness and rigidity of the road bed and the weight of the traffic expected; a 6-inch layer is sufficient for ordinary soils.

Jhama, i.e., vitrified bricks (see Volume I., page 11), broken into fragments 1½ to 2 inches cube and mixed with half the quantity of well burnt bricks similarly broken, makes good road metal. (*R. L. Heinig.*)

The surface of the road bed or formation surface should be thoroughly drained, consolidated, and properly shaped before the stone is added. The transverse profile of the road bed is usually sloping both ways from the centre line towards the sides of the road, the angle of slope being from 1 in 20 to 1 in 30, according to the drainage quality of the soil. The metal should be put on in layers 3 or 4 inches deep, the first layer being consolidated by rolling, or by the traffic passing over the road, before the second layer is added. When rolling a road always commence at the sides and work towards the middle; if rolling is commenced at the centre and proceeds towards the sides the metal will spread laterally. If the first layer of metal is consolidated by traffic the ruts formed in it should be promptly filled up by raking stones into them from either side.

When the first layer is fairly consolidated the second layer should be added during wet weather, or after the surface of the road has been thoroughly watered. If a third layer is added it should be laid in the same way as the second. The hardest and toughest stone should be kept for the upper layers, while the larger and softer stone should be placed in the lower layers.

Where only a portion of the width of the road is to be metalled, the metalling should be placed on the portion of the road where the heavy traffic travels, and should be well drained.

Metalled roads should, if possible, be consolidated by rolling, as the resulting surface of the road will be more uniform and even, and will wear better than if consolidated by traffic only or simply rammed.

§ 29. *Telford's System* differs from Macadam's in that a layer of large stone blocks is first laid on the flat formation road surface, and upon this solid pavement broken stone is laid as in Macadam's system. It is a better but more expensive, way of metalling a road.

Telford prescribed in the case of the Holyhead Road that upon the level bed prepared for the road materials a bottom course or layer of stones is to be set by hand in form of a close, firm pavement; the stones set in the middle of the road are to be 7 inches in depth, at 9 feet from the centre 5 inches, at 12 feet from the centre 4 inches, and at 15 feet 3 inches. They are to be set on their broadest edges, lengthways across the road, and the breadth of the upper edge is not to exceed 4 inches in any case. All the irregularities of the upper part of the said pavement are to be broken off with the hammer, and all the interstices to be filled with stone chips firmly wedged or packed by hand, with a light hammer; so that when the whole pavement is finished there shall be a convexity of 4 inches in the breadth of 15 feet from the centre.

If the road bed be as hard and rigid as a rock surface, there is no need for a Telford sub-pavement; on soft soils the broken stone on the pavement cannot sink down into and become mixed with the earthen surface; the pavement also acts as a continuous under drain for the road crust.

In both Macadam's and Telford's systems it is necessary to mix with the top layer of broken stone some binding material, to fill the interstices and cement the stones into a compact mass. Fine pea gravel with a proportion of about one-fourth of sandy clay may be mixed with the top layer before deposition or dry powdered clay may be spread over the surface of the rolled layer, and be well brushed into the spaces; or sandy clay may be reduced with water to creamy consistency, and be poured over and well brushed into the interstices of the compacted top layer.

§ 30. KANKAR ROADS.—Kankar is used largely for metalling roads in the plains of India where it is found; it forms a very good and durable road for fairly light traffic. Kankar is laid down in layers 4½ inches deep consolidated to 3 inches. Two layers are generally sufficient; the lower layer should be of block kankar when procurable. The pieces of stone in this layer may be as much as 4½ inches in diameter. The upper layer should consist of small pieces of washed and screened kankar; each layer should be consolidated with heavy rammers while thoroughly drenched with water; a plentiful supply of water is most essential to the thorough consolidation of the road surface, as without it the kankar will not bind properly. The kankar should have three rammings, one when dry, one when wet, and the third when soaked with water.

§ 31. REPAIRING ROADS.—Roads metalled with stone must be kept in a proper state of repair, and this is best done by keeping a small gang of men permanently on the road to execute such petty repairs as may be necessary, each man or gang of men being given a certain length of road to keep in repairs. Ruts and hollows are to be promptly filled up with small pieces of broken stone and carefully consolidated.

When the layer of metalling has worn down to a thickness of 4 inches more metalling should be added. The surface of the road to be re-metalled should be well watered and loosened to a depth of 2 or 3 inches with a pick, so that the new layer of metal, which should be 3 or 4 inches thick, may unite with the old road crust.

Repairs to a kankar road should be done in rainy weather, or the road surface must be very thoroughly watered while the work is going on. The new layer of metal added should be consolidated by rolling if practicable. If the traffic over the road is considerable, only one-half of the width of the road should be repaired at a time.

If a road metalled with kankar is not kept in repair, it is not much better than an unmetalled road. If, however, it is properly looked after, and all ruts and holes promptly repaired, it may be allowed to wear down until the upper layer of kankar has to be renewed. Petty repairs should be carried out all the year round, and any extensive repairs that may be necessary should be executed at the beginning of the cold weather.

When the surface breaks up into holes, the edges of the holes should be cut to a regular shape to the same depth as the centre of the hole, and the cavity thus formed should be filled with small pieces of kankar, to a thickness of 1½ times he depth of the hole, and beaten down to the level of the old surface of the road. The edges of the ruts that are 1½ to 2 inches deep should be cut clean and straight, forming shallow trenches about 2 feet wide, which are filled with small kankar thoroughly compacted.

§ 32. UNMETALLED ROADS.—It is most essential that the surface of unmetalled roads should be kept permanently above the level of the surrounding country, for if the road surface once becomes lower than that of the surrounding country the road soon degenerates into a water channel, and becomes quite impassable for traffic. Consequently, where the traffic is heavy, earth will have to be thrown on the road annually so as to keep its surface higher than that of the surrounding country. If the soil of the road is a stiff clay it may be improved by spreading sand over its surface and rolling it in. If the road passes over loose sand the surface of the roadway may be improved by the addition of dry powdered clay or by spreading grass or brushwood on the road and a foot of earth on the top of this layer. The best season for repairing unmetalled roads is the end of the rainy season, when the soil is still moist and can easily be consolidated and worked. All the ruts and holes should be loosened with a pick and filled with fresh soil taken from the side ditches. This soil should be well beaten down, and the road restored as far as possible to its proper shape.

SECTION III.—THE ALIGNMENT OF ROADS AND PATHS IN THE HILLS AND PLAINS.

§ **33.** It must be distinctly understood that it is impossible to learn how to align a road or path by *only* reading how this important process is done in a book.

After the principles upon which the process of aligning a road or path have been mastered by reading, and are quite familiar, the actual procedure of aligning roads or paths can only be learnt practically in the field.

The process of aligning a road or path is the selection of the exact route which the road or path is to follow. The actual choice of this route is the most important operation connected with road-making. The line chosen will usually form the centre line of the road or path when it is constructed. If the alignment of the road is badly chosen in the first instance, unnecessary expense will probably be incurred in the construction of the road; the annual cost of repairs to it will be greater; and, when a higher class of traffic is brought over the road, necessitating a lower ruling and average gradients (see § 37, page 34), it may be found cheaper to construct an entirely new road rather than alter the existing one, thus sacrificing all the money which has been previously spent on it. If, however, the line is skilfully chosen in the first instance—although funds may not be then available to make the road at first as it will be finally constructed, and although temporary diversions may be necessary in order to avoid physical obstacles which will be gradually removed when money is forthcoming—what has been done will not have to be undone when the road is improved to carry the higher class of traffic.

An error in the method of constructing the surface of the road itself can be easily remedied, but mistakes in the first alignment of a road cannot be so easily overcome. It is most important that the best possible route for the road that can be obtained should be chosen in the first instance. This will require a most careful examination of the country, and the laying out of several trial lines to produce one which, taking everything into consideration, is the best suited for the particular class of road. Such extra preliminary work will always be more than compensated by the ultimate results obtained.

The general principles which govern the alignment of roads and paths apply equally to the different classes of roads enumerated on page 4. After the general direction of a road or path has been determined, the actual line to be followed will depend to a great extent upon the gradients allowed on the road or path in question. Speaking generally, the line which a given road is to follow is practically determined by the gradients which are permissible on it. When the class of road which is to be constructed has been settled, and the difference in elevation between the two points to be joined by the roads is known, as well as the shortest horizontal distance between the two points, then *theoretically* the best road which can be constructed will be one which has a practically uniform gradient, and follows as closely as possible the most direct (*i.e.*, the shortest) line between the two points, provided that the gradient does not exceed the average gradient permissible on the class of road in question.

Practically such a line can very rarely, if ever, be found even in the plains of India. Physical obstacles, such as valleys, ridges, rivers, large rocks, ravines, precipices, cross the direct line between the two places which the road is to join, and the line which the road is to follow must of necessity be altered so as to overcome these difficulties, while having a proper gradient, and at the same time following, as far as possible, the general contour of the country, so as to avoid the construction of large embankments, or the excavation of deep cuttings.

Before commencing to align a road on the ground the best available maps of the country should be obtained, showing the position of the chief markets and centres of production, and the principal existing roads with which the new road may be connected. The new lines of communication should pass through the richest parts of the country and through the largest or most flourishing towns. The country to be traversed should then be examined on the ground, and the map corrected where necessary. The general and physical features of the country through which the road is to pass, as well as those of the adjoining country influenced by the road, should be carefully examined.

It is important to know the total difference in height between the places to be joined by the road, and also the heights of the tops of the ridges and the bottoms of the valleys crossing the line which the road has to follow.

The country through which the road is to pass is examined in detail, map in hand, special attention being paid to the river crossings, the valleys and ridges, and particularly to any difficult and broken ground through which the road may have to pass. The gradient to be given to the road must be kept in mind, as it materially affects the choice of a line; and a country through which it would be difficult to make a cart-road may offer comparatively few difficulties to the construction of a bridle-path for pack animals.

The country should be traversed, map in hand, two or three times in both directions, ast he physical features of a country present very different aspects when looked at from opposite directions.

Existing tracks may furnish much information as to the best lines to be followed. When a new forest area has to be opened up a general scheme of roads and paths should be carefully determined before the alignment of any of the roads or paths is finally fixed; and this general scheme should be followed closely, modified if need be as more accurate information becomes available; the roads should be constructed in the order of their relative importance and as funds are available.

§ 34. Before commencing the actual alignment of any road or path the following points must be considered, as they will be found to have a very considerable modifying influence on the actual choice of the line which the road or path is to follow:—

(1) The object for which the road is to be constructed.

(2) The natural features of the country.

(3) The gradients allowed on the road.

(4) The position of the market or markets.

(5) The existing roads.

(6) The proximity of good metalling.

(7) The cost of construction.

§ **35.** *The Object for which the Road is Constructed.*—If the road is to serve as a main export road, it should be made as direct as possible from the forest area to the principal market or markets.

If, however, the object for which the road is constructed is to make the different parts of a forest more accessible, a circuitous road, or one from which branches run up the different valleys or other natural divisions into which the forest is divided, will generally be found to be the most useful.

The roads should be made as near the lower boundary of the forest as possible, so that the produce may be brought down to the road and then transported along it to the market. A road constructed through the upper portion of a forest is practically only of use for that part of the forest which is above it. If a road is carried up a valley, it should follow the bottom of the valley as far as possible consistent with the safety of the road itself, so that the produce from both the slopes of the valley may be taken out along it.

The above remarks apply equally to the alignment of roads in the hills and in the plains.

§ **36.** *The Natural Features of the Country.*—The natural features of the country may chiefly determine the line which the road must follow. In a flat country several routes may be practicable, but in a hilly district or one much broken by ravines the cost of overcoming the unavoidable physical obstacles found on many of the possible lines may render the construction of the road following them out of the question.

Localities which are very liable to land-slips, or sides of valleys which are evidently unstable, should be studiously avoided if possible. If a road is taken across an area which is subject to constant slips, the traffic along it may be either completely stopped for long periods of time or have to be taken along some other more circuitous route.

In laying out a road there are always some points through which the road, either from physical or economic reasons, must pass. These are technically known as *obligatory points.* For instance, the road must cross a large river or a range of hills. In the first case the river may be passable only at certain points of its course, and through one of these the road must pass. In the case of the range of hills the lowest part of the range in the general direction of the road would be chosen. The top or foot of precipitous ground, or a large rock which it would be too expensive to remove, often forms an obligatory point in the alignment of a hill road.

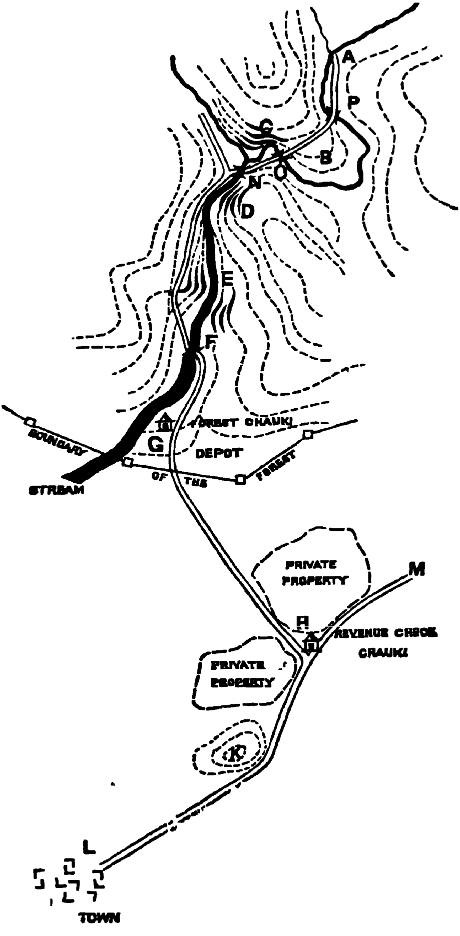
When a difficult piece of country has to be traversed and comparatively easy ground lies on either side of it, the best practicable line through the bad portion should be selected, each end of this line will form a point to which the road must be aligned through the easier portions of the country.

The position of important towns, of valuable pieces of cultivated land, and of plantations and the sources of supply of material for metalling often form obligatory points in the alignment of a road.

In the plains, besides towns and cultivation, we may have to avoid swampy ground, local depressions and rises, ground where the cost of repairing the road would be excessive, or where an expensive scheme of drainage would be necessary in order to render the road passable to traffic.

Figure 8 illustrates the alignment of part of a road, showing how difficulties of a physical nature may be avoided. A *is the point above which it is not economical to make a road.* B *is low-lying land near the bed of the stream.* C *and* D *are cliffs which must be avoided.* E *is also a high cliff to be avoided, and the road rises after crossing the stream as quickly as the gradient will allow, and passes over the cliff at* E, *avoiding that at* D. *The road must re-cross the river at* F *as it is the narrowest part of the stream. The stream widens out quickly below this point.* G *is the forest guard's house, where the export produce is examined ; and* H *is a revenue check station where the forest produce is again inspected. The road must pass through* G H, *and therefore cannot run straight to the market situated at* L. *The road has also to avoid the pieces of private property shown and also the hill* K. *Bridges will have to be made across the stream at* P, O, N *and* F. *The broken lines are contour lines.*

FIG. 8.


A
P
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FOREST CHAUKI
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DEPOT
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OF THE
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REVENUE CHECK CHAUKI
PRIVATE PROPERTY
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L
TOWN

§ 37. *The Gradients allowed on the Road.*—The *gradient* of a road is the inclination of the plane in which the road lies to the horizontal plane. The *ruling gradient* of a road is the steepest gradient permissible for the class of traffic which is to pass over it. The following table gives the *ruling gradients* for the different kinds of roads in common use :—

For foot-paths for laden coolies	1 in 3
,, bridle-paths for horses	1 in 5
,, ,, for pack animals	1 in 7
,, roads for camels	1 in 8
,, fair-weather roads for small carts	1 in 15
,, roads for high-class wheeled traffic	1 in 20

The higher the class of wheeled traffic the lower should be the ruling gradient.

It should be remembered that these are the absolute maximum gradients which can be adopted for the different classes of roads and paths given. These gradients can only be used for short distances (200 or 300 feet), and only when absolutely necessary. Such gradients should always be immediately followed by similar lengths of road with a gradient not exceeding, and if possible lower than, the average gradient of the road in question.

The *average* gradients for the above classes of roads when the object is to ascend from one place to another should be as follows :—

Foot-paths for laden coolies	1 in 5
Bridle-paths for horses	1 in 7½
,, for pack animals	1 in 10
Roads for camels	1 in 12
Fair-weather roads for small carts	1 in 25
Roads for high-class wheeled traffic	1 in 50

In the above tables the first figure indicates a vertical height, the second a distance which for convenience may be measured along the surface of the road ; for example, a gradient of 1 in 5 means a rise of 1 foot vertically for every 5 feet measured along the road. It must be noted that these ratios do not represent the actual magnitude of the gradient as defined above, but so long as the angle of inclination is small, as it is in the case of a road, the error is practically too small to be of any consequence.

The quality of a road, so far as its value as a means of export is concerned, depends upon that of the steepest portion on it, as this will determine the maximum load which can be taken along it.

Slow traffic can without over-exertion of the draught animal ascend gradients as steep as 1 in 16 or 1 in 20 even, where the ascents are continuous for several miles. For single ascents (where the country is not undulating) exceeding 5 miles gradients of 1 in 16 or 1 in 20 are too severe; in such cases the gradient should not exceed 1 in 24, and with this gradient 10 miles of continuous ascent can be surmounted without a halt or undue exertion on the part of the draught animals.[1]

§ 38. In the *hills* the following points require special attention —

(*a*) The road or path should never rise or fall unnecessarily, and should be taken round, either below or above obstacles which are too expensive to remove without exceeding the ruling gradient.

(*b*) The quantity of ascent and descent should be divided as evenly as possible over as long a distance as the nature of the ground will permit of, in order to make the gradient as generally uniform and as low as possible.

(*c*) Zig-zags should be avoided; they are difficult to lay out, and the sharp turns are dangerous to the traffic on the road, and can rarely be utilized for a higher class of traffic than that for which they were originally constructed. The drainage of zig-zags without risk of damage to the road is difficult, and on unstable ground the road itself may be endangered. It is generally possible to carry an inclined roadway up a slope without reversing its direction, or by making one or two turns at the most in the direction of the road.

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[1] "A Treatise on Mountain Roads," by General H. St. Clair Wilkins, pages 70, 71 and 72. London, 1880.

(*d*) The sunny side of a valley or the side exposed to drying winds should generally be chosen where practicable, as the road surface will be drier. In hot districts the shady side should be selected for the sake of coolness.

(*e*) The gradient of the road should be most carefully maintained, and the ruling gradient should never be exceeded. Long stretches of road with absolutely the same gradient should be avoided. The same gradients should be maintained for at least a quarter of a mile if practicable. A road can be made much less tedious by laying out the gradient alternately slightly steeper and gentler than the actual gradient necessary to take the road from one fixed point to another.

(*f*) When the slope of the ground is less than the mean gradient of the road which is being aligned, the road should be made as straight as possible. When a ravine runs far into the hill-side the line should not always be taken all the way round the ravine at a gentle gradient but may descend until the bottom of the ravine is, crossed, and then ascend again to the same level if this is necessary.

(*g*) Every possible effort should be made to avoid taking roads through places where there is much risk of landslips.

(*h*) The water supply of the road must also be attended to. If the road is many miles in length (10 miles and upwards), it is necessary that water should be available for the draught cattle, otherwise the want of water *en route* may absolutely prove prohibitory of the adoption of a line favourable in other respects.[1]

(*i*) Convenient halting-places should be made if the road exceeds 5 miles in length. Plateaux which may occur contiguous to the road, should be made easy of access, so as to obviate the necessity of the carriers halting their vehicles on the road itself.

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[1] "A Treatise on Mountain Roads," by General H. St. Clair Wilkins, page 9. London. 1880.

§ 39. In the *plains* the transport of forest produce by carts is cheaper than by pack animals or by coolies; consequently roads made in the plains are for the most part constructed for cart traffic. The gradient to be given to the cart-road depends upon the size and nature of carts used, the strength of the draught animals, and whether the road is metalled or unmetalled. The gradient of a metalled cart-road constructed for a high-class wheeled traffic should never exceed 1 in 30; for unmetalled roads which are less important 1 in 20, and where small country carts are used it may be 1 in 15 for short distances. Where laden carts move in one direction only, as is often the case in the transport of forest produce, steeper down gradients than those given above may be allowed in the direction of the loaded traffic.

On unmetalled roads, which are rough and produce great friction, steeper gradients are allowed than on metalled roads with smooth hard surfaces, because the increased tractive power required on such a rough road would carry the load over steeper gradients than could the tractive power just required for the load on a level metalled road. The bad road of course requires actually greater tractive power than the good one, and the same tractive power being used for both, the number of working hours and the distances travelled on the good road with a hard surface becomes reduced on the bad road with the rough surface.[1]

Where the country is very flat, slight deviations from the straight line should be made in order to break the monotony of an absolutely straight road; short reversed curves at intervals of 3 miles will effect this without materially increasing the length. The sides of the road at the reverse curves may be planted with trees. It is often advisable, where the country is very flat, to give the road a series of short longitudinal slopes, to facilitate the proper drainage of its surface a minimum slope of 1 in 125 is commonly adopted.

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[1] "A Treatise on Mountain Roads," by General H. St. Clair Wilkins, pages 58, 59. London, 1880.

§ 40. *The Position of the Market or Markets.*—A road should not necessarily go straight to the principal market, but should be aligned so as to pass near or through such places as are likely to become markets for the produce of the forests.

§ 41. *Existing Roads.*—In laying out a new road considerable attention should be paid to the direction of such roads as are already in existence, in order that the new road may join conveniently on to those which already exist, so that they may be utilized as far as possible for the extraction of the forest produce.

§ 42. *The Proximity of Good Metalling.*—This may be occasionally of considerable importance in the plains, where good road metal is often scarce. It is sometimes advisable to change the direction of the road slightly, if it is to be metalled, in order that it may pass through places where good metalling is to be obtained, if thereby the cost of the construction and up-keep of the road will be materially lessened.

The supply of good material should be ample not only for the construction of the road but also for its future maintenance

It has been calculated[1] that between A and B, a distance of 40 miles in the plains, if the road is aligned anywhere within the parallelogram ADBC (see Fig. 9), where CD is 8 miles long the length of the road will, other conditions being the same, be increased by only 2 per cent., and if good metalling is to be obtained within that area the road should pass near the spot where the road metal is found.

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[1] Roorkee "Treatise on Civil Engineering," Vol. II., page 216, § 251, 3rd Ed., 1877.

FIG. 9.

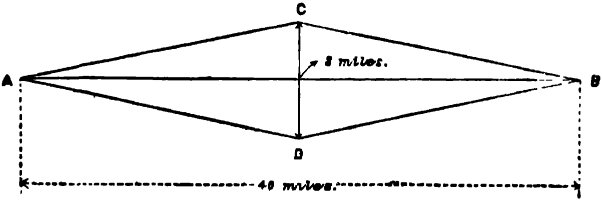

Figure 9 is a diagram to show to what extent the alignment of a road may depart from a straight line in order to bring the road near a locality where good metalling exists.

§ 43. *The Cost of Construction.*—The following information[1] may be useful in helping to determine which of two alternative routes will be the cheaper to adopt.

The cost of 1 mile of embankment 4 feet high is equivalent to the cost of 36 feet of waterway in small bridges, or 10 feet of waterway in large bridges, or to $\frac{1}{8}$ of a mile of metalling. In important roads deviations are rarely necessary in order to avoid earth-work only.

The cost of construction of a cart-road in the plains is much less than that of a similar road in the hills, on account of the smaller quantity of rock which has to be removed and to the ease with which a line with gradients generally suitable for the road can be found.

§ 44. THE ACTUAL ALIGNMENT OF ROADS IN THE PLAINS.—In aligning a road *in the plains* the following points require careful consideration:—

(*a*) The height of the road surface above the natural surface of the ground to raise it above ordinary floods.

(*b*) The provision of a sufficient waterway for the passage of streams or rivers when in extremely high flood, and for any natural drainage intercepted by the road.

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[1] Roorkee "Treatise on Civil Engineering," Vol. II., page 215, § 249, 3rd Ed., 1877.

(*c*) The choice of sites for the principal bridges, especially with regard to the selection of good foundations for their piers and abutments.

(*d*) The careful determination of the number and dimensions of the spans of a bridge.

(*e*) The best method of constructing the bridges at the least cost consistent with the requisite strength.

(*f*) The comparative rates of the carriage of materials to the road and of the labour employed on it.

(*g*) If the road is to be metalled, the nature of the road metal procurable, the distance of the quarries from the road, as well as the materials available along the road for building purposes.

Roads in the plains consist as a rule of long straight portions joined by gentle curves; the straight portions may be laid out with a prismatic compass, or, if this instrument is not available, by ranging flags exactly one behind another so as to form a straight line. If a straight road is aligned by means of flags (straight bamboos or poles with flage attached to their upper ends) great care must be taken that the flags are placed exactly behind one another, because any error, however slight it may be, to begin with, will be carried on throughout the rest of the line, and the deviation from the intended straight line will increase with the length of the road.

§ 45. To mark out a straight line with flags—

(1) Put in two flags No. 1 and No. 2 in the exact line that should be taken.

(2) See that flags No. 1 and No. 2 are perpendicular by means of a plumb-line, or stone tied to the end of a piece of string.

(3) Send a man ahead with the 3rd flag.

(4) Stand two paces behind the 1st flag, shut one eye and place yourself so that flags No .1 and No. 2 coincide, *i.e.*, flag No .2 becomes invisible on account of flag No. 1.

(5) Guide the 3rd flag man into position so that the bottom of the flag staff coincides with Nos. 1 and 2 and becomes thereby invisible.

(6) Fix flag No. 3 in that place, and make it perpendicular by means of a plumb-line.

(7) Proceed with flag No. 4 in a similar manner, placing yourself behind flag No. 2, and so on for any number of flags.

When the alignment of the road has been finally chosen these flags will be replaced by pegs, marking the centre line of the road as well as of all bridges, culverts, embankments, and cuttings.

§ 46. ALIGNMENT OF ROADS AND PATHS IN THE HILLS.—Ordinary forest roads must be cheaply constructed, and are to be carried round spurs and the heads of valleys and depressions, thus avoiding the necessity for constructing stone revetment walls, embankments or cuttings. It is always better, and also more economical, to cut into a hill-side (unless it is made of hard solid rock) than to make the road or path partly on embankment, if the latter requires a revetment wall to support it

Obligatory points (see page 32, § 36,) are first fixed and trial lines laid out to discover the best line between these points. These trial lines are cleared of vegetation for a width of 2 or 3 feet, and stakes put down to indicate the actual line marked out.

Before laying out any of the trial lines the difference in elevation between the two points to be joined by the road or path (see page 44, § 49,) should be ascertained as accurately as possible, and also the distance in a straight line from one point to the other, so as to get some idea of the average gradient which the road or path should be given. An example will make this statement clearer. Suppose a bridle-path for mules is required between A and B, and the difference in elevation is found to be 200 feet, and the distance from A to B in a straight line is one mile (5,280 feet). Then if the road be made perfectly straight from A to B the average gradient of the road will be 200 in 5,280, or a little less than 4 in 100; and this will be the gradient which we shall begin to lay out the first trial line with.

It will nearly always be necessary to lay out several trial lines before a suitable one is found, especially if the country through which the road is taken is difficult. Steep gradients should where practicable be confined to the lower portions of long ascents.

The advantages of the different trial lines laid out should be carefully considered before any one is finally chosen.

If the forest officer who is laying out the trace for the road or bridle-path has had practical experience in laying out and constructing mountain roads, it will be safe to give him the ruling gradient fixed upon for the finished road to lay out his trace with; but if such an instruction is given to an officer who has had no practical experience in laying out roads and paths, and he is left entirely to his own resources, the finished road will be sure to have steeper inclines than was intended, as the inexperienced officer will be sure to run his ruling gradient too fine in many places when laying out the trace.[1]

The following rules will be found useful for the guidance of forest officers when laying out the trace of a road or path:—[2]

(1) At re-entering angles where a drain, culvert, or bridge will be made the line should be laid out quite level.

(2) At sharp angled salients the chord of the curve should be taken through, level.

(3) At less prominent salients the chord of the curve should be taken through with a slight inclination.

(4) At easy salients the curve should be carried round at a fairly steep gradient.

As a general rule, the alignment of a road or path in the hills should be commenced at the highest point and carried down hill. No attempt should be made to fix the exact position of the road at the foot of the hills, or at the bottom of an intervening valley, although its position may be located in a general way, since the lower slopes of mountains are usually flatter than their summits, and afford a greater choice of routes and levels[3]

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[1] "A Treatise on Mountain Roads," by General H. St Clair Wilkins, page 5. London, 1880.

[2] *Ibid.*, page 108

[3] *Ibid.*, pages 4, 6.

If a forest officer has to make a road at a fixed ruling gradient (as is the case in the alignment of sledge-roads and slides), or at gradients generally approaching that ruling gradient, only one point on the road can be fixed, and that point should be the highest point on the road, sledge-road or slide.

§ **47.** Obstacles which must be overcome are often met in the laying out of trial lines. If small trees or branches come in the way, they should be cut; where the line runs into a large tree it will usually be sufficiently accurate to mark out the line up to the tree and begin again from a point diametrically opposite on the other side of the tree at the same level as that to which the line has been taken.

If rocky or precipitous ground through which it would be expensive to make a road be encountered, the centre line should be set out afresh for a distance varying with the height of the obstacle; and by increasing or decreasing the steepness of the gradient the new centre line can be taken either above or below the obstacle.

The most direct line that is practicable should be followed, and if any deviations from this line are necessary, the original line should be returned to as soon as the physical obstacles to be overcome will allow of this being done.

If the precipitous ground is too extensive to be avoided, the best line through it should be selected and joined up to that portion of the line which has already been laid out. Whether the gradient of the line should be increased or decreased in order to avoid any obstacle met with, depends upon the relation of the gradient at which the line is being laid out to the mean and ruling gradient for the road which is being constructed, and also upon the nature of the ground beyond the obstacle.

It is often advisable to take the line through a rock at one point in order to avoid more serious difficulties further on. The trial lines should be marked out with flags placed at convenient distances, varying with the nature of the ground passed over, and also at points where the direction of the line changes materially. When the line has been definitely selected, it is marked out with small stout pegs driven in along it at short intervals. Two pegs should be placed at each point, a short one whose top shows the actual level of the road surface, and the other 5 or 6 feet high to ensure that the position of the short peg may be readily found. If the path or road is not to be constructed immediately, it is a good plan to dig a small trench from peg to peg, running round obstacles, not over them, in order to prevent the exact line from being lost.

§ 48. The final selection of the line requires the exercise of great care and judgment, and the trial lines should be gone over very carefully in both directions before the actual alignment of the road is definitely chosen. If it is necessary to make some portion of a road steep, the lower portion should be made steep and the upper portion given a gentle gradient.

The operation of aligning a road is a very cheap one, as beyond the cost of the ordinary establishment it only involves the pay of the few coolies who are employed in clearing the line. Consequently it is advisable to spend a good deal of time searching for a good line over a difficult piece of country, rather than to accept the first line which appears fairly suitable, as unless the best possible line is chosen at the outset the cost of making the road may be considerably increased.

§ 49. THE USE OF AN ANEROID BAROMETER IN FIXING THE OBLIGATORY POINTS AND AS AN AID TO THE ALIGNMENT OF A HILL ROAD.—An aneroid barometer is an instrument for ascertaining the pressure on a surface due to the atmosphere, and can be used to obtain the comparative altitude of places. This instrument is very useful in determining which of two alternative physical obligatory points should be selected, and in ascertaining the comparative elevations of places which are fairly close together, and when the distance between these points is known, in determining approximately the mean gradient of the road joining them.

It may also be used to determine the comparative elevations of passes in mountain chains or of depressions in ridges which have to be crossed, as well as the difference in altitude between two alternative river crossings.

To avoid serious errors two instruments should be used. One should be kept at the starting-point of the day's work and read at fixed intervals during the day, and the other should be taken to the places the comparative heights of which are required, and should be read at those places, noting the time of reading, and also at the same fixed intervals of time as the stationary barometer is read. The two barometers are compared at the beginning and end of the day's work, and the difference in reading, if any, noted and allowed for when deducing the comparative heights

It is a good plan to traverse each day's work in both directions, as by so doing you get two readings at each place, the one checking the other. The stationary barometer shows any differences in the readings due to variations in local atmospheric pressure only. These readings may conveniently be plotted on a diagram, and a line through the plotted points will give the curve of variations of atmospheric pressure.

The use of two aneroid barometers as described above is of material help in fixing the physical obligatory points of a road, as well as in determining generally its alignment.

Aneroid readings should be taken in settled weather only when the barometer is fairly steady, and is not liable to sudden atmospheric disturbances.

Other obligatory points, such as towns, etc., are fixed arbitrarily.

SECTION IV.—INSTRUMENTS USED FOR LAYING OUT ROADS.

§ 50. The theodolite and level are used for finally laying out important roads and railways where absolute accuracy is necessary; but for ordinary roads and forest paths generally, where the same degree of accuracy is not required, some more expeditious method must be employed. Forest roads or paths may be aligned with—

(1) The staff and rope.
(2) Abney's Level.
(3) Manson's Road-tracer.
(4) A clinometer.

In the plains, where the country is level, a road may be laid out in a perfectly straight line by ranging flags, but where the ground is uneven one of the instruments enumerated above should be used to align the road or path at suitable gradients.

Abney's Level, Manson's Road-tracer, or a clinometer are well suited for laying out hill roads at any given gradient between obligatory points. They are simple instruments, easily understood, and, if carefully used, are not liable to get out of order. An experienced person can lay out 2 or 3 miles of trial lines in a day through a forest if the undergrowth is not sufficiently thick to interrupt the line of sight.

In laying out in the plains a road perfectly straight between two points 2 or 3 miles apart, and not visible one from the other, if the direction of the line be known, it can be set out by ranging flags. To find out this direction the position of the two points to be joined is marked on the map, take off the bearing of the line joining them with a protractor, apply to it the variation of the magnetic needle, set up a prismatic compass, or plane table furnished with a circular card-board protractor, on the ground at one of the points to be joined, and lay out the corrected bearing.

The direction of the line will then be fixed, and we can prolong it to any required distance by ranging flags (see page 40, § 45).

Another simple way of ranging a straight line between two points is to light a fire at one of the points and to range the road from the other end in the direction of the smoke. (*A. L. Home.*)

The method of joining the straight portions of a road by suitable curves is described later on (see page 73, § 66).

§ **51.** THE STAFF AND ROPE.—This method of aligning a road or path is admittedly not nearly so accurate as the others which are described, and should only be used when none of the recognized instruments for determining gradients are available. Paths aligned with this instrument are infinitely better than those which are aligned by the eye only, or which are not aligned at all.

Description of the Instrument.—This instrument consists of a T-shaped wooden staff usually about 5 feet long, shod with an iron spike so that it can be easily forced into the ground; when set up, the height of the top of the staff above the ground should be exactly 5 feet, or at the height of the observer's eye. A spirit level is fixed to the top of the staff, so that when the staff is vertical the bubble of the level is in the centre of its run, or a plummet may be used. A measured length of cord marked at every 5 feet, or to convenient lengths, is also required. The total length of the cord required will be given by the ratio of the flattest gradient to be set out.

The instrument may be used for laying out roads either going up or going down hill. The gradient laid out by this instrument depends upon the ratio which exists between the height of the staff above the ground and the length of rope used.

Method of use.—When the line is being traced uphill the staff is pressed into the ground and the bubble of the spirit level brought to the centre of its run, the rope is fastened to the top of the staff, and is stretched accurately horizontal, with its free end resting on the hill-side, a peg is put in at this place, the staff is removed to the peg, and the same operation continued.

If the height of the point on the staff to which the cord is fastened above the ground is 5 feet and the length of rope used 50 feet, the gradient of the line traced will be 1 in 10

By altering the relation of the length of the rope to the height of the staff above the ground surface any required gradient may be obtained. Figures 10 and 11 illustrate the method of using this instrument.

FIG. 10.

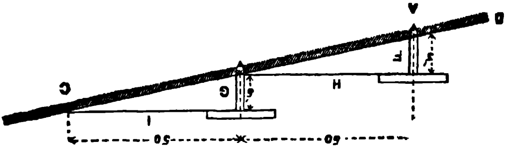


FIG. 11.

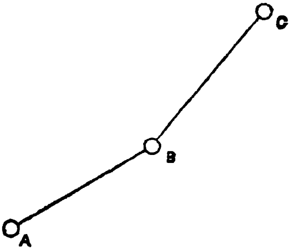


Figure 10 is a section and Figure 11 a plan to illustrate the method of laying out a road uphill at a gradient of 1 in 10 by means of the staff and rope. The horizontal distances between A B *and* B C *are 50 feet, the vertical height between* A *and* B *and* B *and* C *are both 5 feet. Pegs are placed at the points* A, B *and* C *after their position has been determined.* D E *is the surface of the ground,* F, G *are the staves,* H, I *the pieces of rope stretched horizontally.*

The smaller the gradient required the longer the piece of cord necessary; for example, suppose we wish to lay out a line suitable for a bridle-path, *i.e.*, one with a gradient varying between 1 in 7½ and 1 in 10.

If the staff is 5 feet high, in order to get the gradient of 1 in 7½ we shall require a piece of cord 5 × 7½=37½ feet long, but to obtain a gradient of 1 in 10 we shall want 5 × 10=50 feet of cord; so that if we take a piece of string 50 feet long with a knot tied at a distance of 37½ feet from one end, we can lay out the road within the required gradients.

The staff is set up vertically, and the direction of the cord altered until the knot touches the ground (the rope being horizontal) if a gradient of 1 in 7½ is required, or until the end of the rope touches it if a gradient of 1 in 10 is wanted.

If the rope touches the ground anywhere between the knot and the end of the rope, the gradient of the line laid out will be between 1 in 7½ and 1 in 10.

If the line is being traced downhill a second rod (see Fig. 12) twice the height of the staff will be necessary.

FIG. 12.

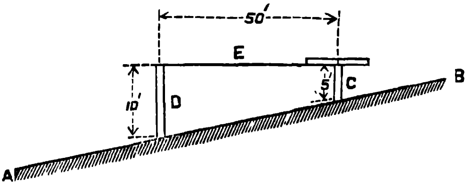


Figure 12 shows the method of laying out a road downhill with a staff and rope. A B *is the surface of the road,* C *the staff,* D *the second staff, and E the rope stretched horizontally.*

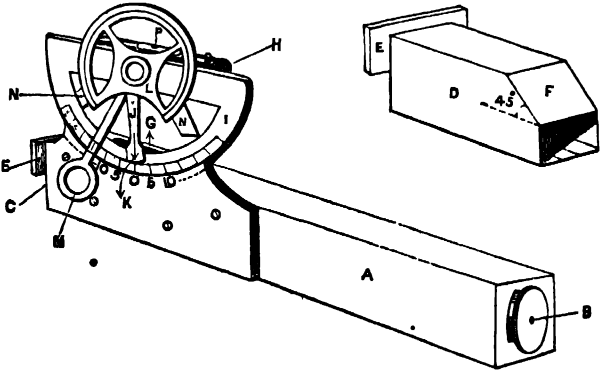
§ 52. ABNEY'S LEVEL. *Description of the instrument* — Abney's Level (see Figs. 13 and 14) consists of a square tube (A) about 5 inches long and of ½ inch side; one end of the tube is closed with the exception of a pin-hole (B) pierced at the centre of the end of a smaller tube, circular in section, which fits into the main tube (A) of the instrument and serves as an eye-piece. This inner tube can be pulled out to focus objects at different distances. The other end of the tube (C) is sprung so as to receive an accurately fitting short square tube (D, Fig. 14). A flange (E) is fixed to the upper half of the outer end of this tube, by means of which it can be removed from the main tube when necessary.

The upper half of the inner end of the short tube is closed by a mirror (F), fixed at an angle of 45° with the longitudinal axis of the tube.

The lower horizontal edge of this mirror is exactly in the optical axis or line of sight of the instrument.

An opening (G) ½ an inch long and ¼ of an inch wide is cut in the upper surface of the main tube (A) of the instrument above the lower edge of the inclined mirror. Immediately above this opening is fixed a small spirit level (H), movable about its centre in a vertical plane. The centre of the bubble tube, in whatever position it may be in, is always vertically above the lower edge of the mirror and the optical axis.

FIG. 13. FIG. 14.



Figures 13 and 14 are sketches to illustrate the construction of Abney's level. The letters in the sketches are those referred to in the description of the instrument. N *a portion of the metal bracket which carries the level tube, and* P *the air bubble in the level tube, are not specially mentioned in the description of the instrument.*

Figure 14 shows the construction of the short tube which is sprung o allow of its fitting accurately into the main square tube of the level.

This spirit level is fixed to a metal bracket N. A fixed semi-circular vertical graduated arc (I) is fastened to one side of the main tube of the instrument. The arc is graduated from mid-length in each direction to read degrees directly, and differences of 10 minutes by means of a vernier arm.

The bracket (N) which carries the spirit level (H), and the index (G) are fastened to a horizontal axis, which works in the upper part of the graduated arc (I) as a collar. This axis ends in the mill-headed wheel (L), and when this wheel is turned round the vernier arm (J), the bracket (N) and the spirit level (H) attached to it are rotated through the same angle. The vernier arm (J) is fixed at right angles to the plane of the level. The centre point of the vernier arm (K) is marked with an arrow, and serves as an index by means of which the angles on the vertical graduated arc are read. The zero point of the vernier coincides with this arrow, and the vernier is graduated on both sides of the zero point. A magnifying glass (M) is sometimes attached to the scale in order to enable the graduations on it to be read more accurately.

It is an advantage to attach a clamping screw to the bar carrying the bubble tube, so that the bar can be rigidly attached to the quadrant when the angle has been set.

When the index on the vernier arm coincides with the zero point on the vertical scale, the plane of the level tube is parallel to the optical axis of the instrument, while if the optical axis be inclined to the horizontal, and the level tube be moved till the bubble is brought to the exact centre of its run, the index will show on the graduated arc the angle of the inclined position of the level to the optical axis.

If the spirit level be turned through any angle, *i.e.*, if the longitudinal axis of the spirit level be inclined at any angle to the optical axis of the instrument, the index will pass through the same angle, and its magnitude will be shown by it on the scale engraved on the vertical arc.

The scale on the vertical arc is graduated from its centre in both directions, and by turning the index either to the right or left of the zero point through any angle (according as an angle above or below the horizontal plane is required), the plane of the spirit level (H) is inclined at the same angle to the optical axis of the instrument. In order to bring the bubble back to the centre of its run, *i.e.*, bring the level tube (H) back into a horizontal plane, the main tube of the level (A) must be tilted through the same angle as is shown by the index on the vertical scale.

When the bubble of the spirit level (H) is at the centre of its run, the mirror (F) reflects half of the bubble of the spirit level (H), the centre of which is vertically above the lower edge of the mirror, along the optical axis of the instrument, and it is thus visible to the eye of an observer placed at the eye-piece of the instrument. As the mirror occupies exactly the upper half of the tube, its lower horizontal edge serves the same purpose as the horizontal wire of the diaphragm of the Dumpy Level

Besides the level a cross staff with a sliding vane (see Fig. 15) is required. The vane usually consists of a piece of wood 4" × 3" × ½", painted white, with a horizontal black line marked across its centre.

FIG. 15.

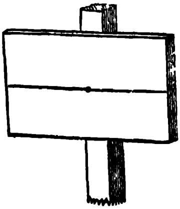


Figure 15 shows the upper portion of a cross staff with an adjustable vane used with Abney's Level. The staff is rectangular in section. An iron socket which is fastened to the back of the board is made slightly larger than the staff, to allow of its being moved up and down it as required. The vane is fixed in any required position by means of a small wooden wedge placed in the socket.

A plummet attached to the staff enables it to be placed in a vertical position. The centre of the black line may be marked with a dot. The Abney's Level should be placed on the top of a rod, and the black line of the vane should be adjusted so as to be the same height above the ground as the eye-piece of the level is. If the level is not placed on a rod, the black line on the vane must be fastened so as to be the same height above the ground as the eye of the person who is using the instrument.

§ 53. USE OF THE INSTRUMENT.—The instrument should be first tested in order to see if it is in adjustment or not (see page 55, § 54), and if out of adjustment corrected as explained in that paragraph. A horizontal or inclined line can be laid out with Abney's Level. To set out a horizontal line the index is set to the zero point of the scale, and the cross staff, adjusted to suit the height of the observer, is sent on in front to *any* convenient distance less than 100 feet. The distance should not be too great, as the eye-piece of the level has no magnifying power.

The observer, holding the level in his hands on the top of a rod, then looks through the eye-piece of the instrument and tilts it until the image of half the bubble is seen in the mirror just above its lower edge. When the observer sees the reflection of half the bubble at the eye-piece, he knows that the spirit level tube is truly horizontal; then if at the same time the black line of the vane of the cross staff coincides with the lower edge of the mirror, the point where the sight vane is held is on the same horizontal plane as the point where the observer stands. If the index is set to 0°, the line traced by the level is a horizontal one, because the plane of the spirit level (H) is parallel to the axis of the instrument when its bubble is in the centre of its run.

If the black line on the vane of the cross staff (when the reflection of half the bubble is seen as described above) is above the lower edge of the mirror, the vane of the cross staff is too high, and the cross staff must be placed on lower ground; if, on the other hand, the vane of the cross staff is below the black line, the cross staff must be placed on higher ground until the lower edge of the mirror may coincide with the black line on it at the same time reflection of half the bubble is seen at the eye-piece. Figure 16 shows the relative appearance, as seen by an observer, of the bubble and sight vane when the latter is correctly placed on the ground. The sight vane staff must be held vertical.

FIG. 16.

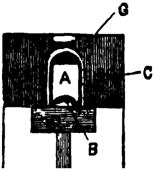


Figure 16 shows the appearance of the bubble and vane of the cross staff as seen at the eye-piece of the Abney's Level when the vane of the cross staff is in the correct position. The mirror (F, *Fig. 14*) *reflects part of the glass tube of the spirit level* A, *half of the bubble* B, *its metal frame* C, *the opening* G (*in the upper surface of the tube of the instrument*) *and the inner surface of the square tube; this latter appears dark. The centre line of the vane of the cross staff coincides with the lower edge of the mirror, so that only one-half of the vane of the cross staff* D *is seen below the mirror.*

A peg should be driven in where the observer stands and also where the cross staff is held. The observer then goes to the second peg, sends on the cross staff to any convenient distance and repeats the same operation; the surface of the ground at the pegs is in the same horizontal plane.

If it is required to lay out a line uphill inclined at any angle (say 2° 52′, the angle corresponding to a gradient of 1 in 20) the index of the vernier should be set to 2° 50′ to the right of the zero point, as this is the nearest approximation we can obtain to the required angle. The sight vane, adjusted to the height of the observer's eye, or the top of the rod on which the level is placed, is then sent on to a convenient distance. The bubble and black line of the cross staff are then adjusted in exactly the same way as was described when a level line was being laid out. The line laid out will have the gradient indicated on the scale on the vertical arc (I), because since the plane of the spirit level has been turned through 2° 50′ the instrument must be tilted through the same angle before the bubble is brought back to the centre of its run, and in that position only is its reflection visible to an observer at the eye-piece of the level.

To lay out a line downhill, the index is moved to the required angle to the left of the zero point of the scale on the vertical arc (I).

§ 54. ADJUSTMENT OF ABNEY'S LEVEL.—In order to test whether the instrument is in adjustment or not, we should proceed as follows. Set the index of the vernier arm (K, Fig. 13,) to any convenient angle on the graduated vertical arc (I, Fig. 13,) corresponding to any required slope, say, 5 degrees. Send a properly adjusted cross staff on ahead and fix a point by driving a peg into the ground, so that the cross staff when placed on the top of this peg, is correctly intersected by the level, placed on a rod resting on another peg. Change the positions of the cross staff and level. Tilt the plane of the spirit level by rotating the mill-headed screw (L, Fig. 13,) until the black line on the vane of the cross staff (Fig. 15, page 52,) is correctly intersected. If the instrument is in adjustment, the angle shown by the index of the vernier should also be 5 degrees. In one case the index will cut the scale on the vertical arc to the right, and in the other case to the left, of its zero point.

If the two readings do not coincide, the true inclination of the line laid out will be the mean of the two readings obtained. The instrument should be set to *this mean angle* and the plane of spirit level itself altered very slightly by raising or lowering the screws which will be found underneath it, and by which it is attached to the bracket (N, Fig. 13,) until the cross staff placed on one peg is cut by the level put at the other. When this adjustment has been made, the positions of the level and cross staff should be interchanged, and the plane of the spirit level altered by turning the mill-headed wheel until the cross staff is correctly intersected as described above, then the angle shown by the index of the vernier should be the same as that to which it was originally set.

If a Dumpy Level is available, two pegs can be laid down at a fixed distance apart, and at a fixed and known vertical height one above another. The level should then be set to the angle corresponding to the slope between the two pegs laid down. The instrument should be placed on one peg and the cross staff placed on the other, and if the level is in adjustment, the line on the vane of the cross staff should be accurately cut by the level. The pegs put down by means of the Dumpy Level may be fixed at the same level; and in this case the index of the vernier of the Abney's Level should be set at zero degrees. If the instrument is out of adjustment, the plane of the spirit level is brought into the correct position as described above by raising or lowering the tangent screws by which it is fastened to the metal bracket which supports it.

§ 55. The following tables showing (1) the angles which correspond to given inclinations as well as their equivalent gradient in feet per mile, and (2) the inclinations and equivalent rise or fall in feet per mile which correspond to given angles, will be found useful.

Abney's Level may be used to measure the heights of trees and other objects as well as to lay out roads, and for this purpose is more accurate and less liable to get out of order than instruments constructed on the principle of the loaded graduated disc.

Table showing the Gradients calculated from natural sines corresponding to given angles and their equivalent in feet per mile.

Angle expressed in degrees	Corresponding inclination in nearest integers	Equivalent gradient expressed in feet per mile in the nearest integers.
½	1 · 115	46
¾	1 . 76	69
1	1 57	93
1½	1 : 38	139
2	1 29	182
2½	1 23	230
3	1 19	278
4	1 14	377
5	1 : 11	480
6	2 : 19	556
7	1 · 8	660
8	1 : 7	754
9	1 6	880
10	2 : 11	960
11	1 : 5	1,056
12	5 : 24	1,110
13	20 89	1,186
14	1 : 4	1,320

Table showing the angles calculated from their natural sines corresponding to given inclinations and their equivalent feet per mile

Inclination	Corresponding angle to nearest minute.		Equivalent gradient in feet per mile.
	Degrees	Minutes	
1 : 3	19	28	1,760
1 : 4	14	29	1,320
1 : 5	11	32	1,056
1 : 7½	7	40	704
1 : 10	5	45	528
1 : 12	4	47	440
1 : 13	4	24	406
1 : 15	3	49	352
1 : 20	2	52	264
1 : 25	2	18	211
1 : 30	1	55	176
1 : 35	1	38	151
1 : 40	1	26	132
1 : 45	1	16	117
1 : 50	1	9	106
1 : 100	0	35	53
1 : 125	0	28	42

§ 56. In an older form of Abney's Level the following arrangement of mirror was used in the short tube D :—A mirror occupying the right hand *vertical half* of the tube is fixed at an angle of 45° with the optical axis of the instrument, under the opening G, the bubble when in the centre of its run being vertically above a horizontal line marked across the middle of the mirror (in the optical axis of the instrument), and in consequence when the bubble is in the centre of its run the reflection of the *whole* bubble bisected by the horizontal line on the mirror, is seen at the eye-piece of the telescope tube. A horizontal wire is placed in the optical axis of the instrument, immediately behind the inclined mirror, and serves to cut the sight vane at the same time as the reflection of the bubble is bisected by the horizontal line in the mirror.

Figure 17 shows the appearance of the bubble and vane to an observer when the cross staff is correctly placed on the ground

FIG. 17.

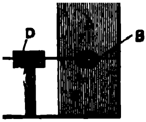


Figure 17 shows the position of the bubble and cross staff as seen by the observer in the form of Abney's Level in which a mirror occupying one vertical half of the tube is used The whole of the bubble B *is seen in the mirror* A, *bisected by the central horizontal line cut on it, and the whole of the vane of the cross staff* D *is seen, its central line coinciding with the horizontal wire in the main tube of the instrument.*

The method of using the instrument is the same as has been described above. In practice, the older form is easier to work with, and is consequently preferable.

§ 57. **Manson's Road-tracer** [1]—The construction of this instrument is based upon the principle that in similar triangles the sides about equal angles are proportional one to another.

The instrument itself is a very simple one, and one that can be made locally by any carpenter. It consists of a well-seasoned solid straight bamboo or wooden staff about 5½ feet long (see Fig 18) shod with iron. This iron shoe is furnished with two arms (J, K), so that the bamboo is always pressed into the ground to the same depth A short bar (A) of well-seasoned, straight grained, moderately hard wood, 12 to 18 inches long and 1 inch square, is fastened at right angles to the length of the bamboo or wooden staff by means of an adjustable screw bolt (B), such as is used to fasten the legs of a plane table to the head of the stand which carries the board, this bar is fixed at the height of the eye of the observer above the ground. A small brass plate (C), in which a pin hole has been pierced, is fastened by a screw to one end of the bar (A), and serves as an eye-piece A brass frame (D) bearing a horizontal cross wire or hair is similarly fastened to the other end of the bar, the line of sight from pin hole to cross wire is exactly at right angles to the axis of the bamboo staff The pin hole and cross wire must be exactly at the same height above the accurately planed upper surface of the bar (A) A flat batten (E) is fixed to the bamboo, about 3 feet (one metre) below and parallel to the upper bar This batten is best made of a piece of well-seasoned bamboo, and should be let into the staff, so that its surface does not project beyond that of the staff itself It should be fastened to the staff by two screws, so as to prevent the possibility of its being displaced. It should be placed at right angles to the length of the staff, *i e.*, parallel to the bar (A),

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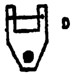
[1] Designed by F B Manson, Esq , Deputy Conservator of Forests, Imperial Forest Service Bengal List

FIG. 19



FIGS 18.

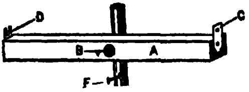
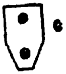
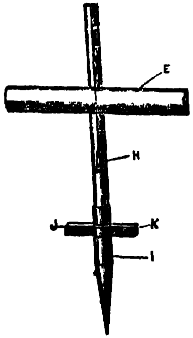


FIG 19





Figures 18 and 19 are sketches of Manson's Road-tracer The whole length of the staff has not been shown A is the upper bar, B the head of the screw bolt by which it is fastened to the staff C is the eye-piece, D the brass frame carrying the horizontal wire which is fixed to the other end of the bar, E is the lower batten upon which the scale is constructed F is the nail from which the plumb line G is suspended, H is the plumb bob, I is the iron shoe, and J, K the arms which ensure its being inserted in the ground to a constant depth

A scale is constructed on the lower batten, and the divisions on it are marked off in both directions from its centre The centre of the scale coincides with the centre of the bamboo staff, and is vertically below the centre of the upper bar. The divisions of this scale are equal, and their length is a fraction of the distance of the graduated bar below the point of suspension of the plumb bob; $\frac{1}{100}$ of a yard or $\frac{1}{100}$ of a metre are recommended. The divisions on the scale should be marked by dots, the 5th, 10th and 15th divisions on either side of zero point being figured 5, 10 and 15 respectively. The centre of the scale should be marked 0.

Exactly one yard or one metre, as the case may be, vertically above the centre point of the scale a small nail (F, see Fig. 19) is driven into the bamboo. A plumb line (G) hangs from this nail, the string of the plumb line being sufficiently long to cut the divisions on the scale. The plumb bob (H) may be made of an empty brass cartridge-case filled with lead, into which a small staple has been introduced while the lead is still liquid. The nail should project sufficiently from the bamboo to allow the plumb line to hang freely.

When the bamboo or wooden staff is placed in the ground so that the plumb line cuts the zero point of the scale on the lower batten, the upper bar will be truly horizontal, and the line traced by the instrument will be a horizontal one. If the instrument be tilted until the plumb line cuts the first division of the scale either to the left or right of the zero point, the angle through which the bamboo staff, and consequently the upper horizontal bar, has been turned is that whose tangent is $\frac{1}{100}$, and the gradient of the line of sight from the pin hole to cross wire 1 in 100, either up or down, according as the plumb line lies to the right or left of the zero point of the scale. If the instrument be tilted until the plumb line cuts the second division of the scale, the gradient of the line traced with it will be 2 in 100, and so on.

§ 58. METHOD OF USE.—To lay out a road with this instrument a cross staff similar to that used with Abney's Level (see Fig. 15, page 52) is required, the sight vane being adjusted to the vertical height of the pin hole of the eye-piece above the ground, which is not materially altered, so long as the bamboo staff is tilted through a small angle only.

The staff is set up with the upper bar in the direction in which the line is to be laid out. The instrument is then tilted until the plumb line cuts the required division on the scale, and the cross staff, held vertical, at any convenient distance from the instrument, is moved up or down the slope until the line on the vane of the cross staff is cut by the cross wire (D, Fig. 19) attached to the upper bar. A peg should then be driven in flush with the ground where the cross staff is held, and a stake put in close by it to prevent its position being lost. The road-tracer is then removed and set up at the peg just put down, and the same operation repeated. The gradient of the line may be altered when necessary by tilting the instrument so that the plumb line cuts another division on the scale. Figure 20 shows how the working of this road-tracer depends upon the principle that in similar triangles the sides about the equal angles are proportional to one another.

FIG 20.

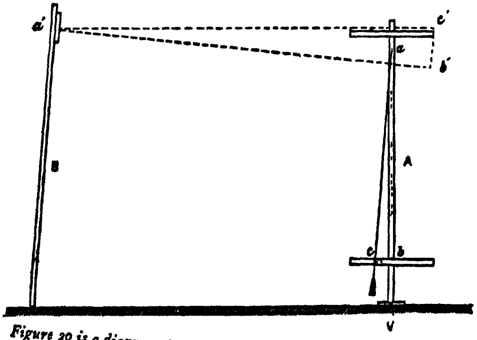


Figure 20 is a diagram to explain the principle upon which Manson's Road-tracer depends. A *is the road-tracer tilted, so that the plumb line cuts one of the divisions on the scale.* B *is the cross staff. The triangles, a b c and a' b' c' are similar, the angles at b and b' being right angles, so that c b : b a :: b' c' : b' a', or the line traced has an inclination expressed by the ratio of c b : b a, which can be made anything we like.*

§ **59.** ADJUSTMENT OF MANSON'S ROAD-TRACER.—Before laying out a road with this instrument we should satisfy ourselves that it is in adjustment. See first that the upper bar (A, Fig. 18) and the scale bar (E, same figure) are at right angles to the staff and parallel to each other.

Then set up the instrument, place the plumb line on the nail, and move the staff slightly, until the plumb line cuts the zero point of the scale; then take an ordinary spirit level 10 or 12 inches long and place it on the top of the upper bar, so that the centre of the level is above the middle point of the bar; if the instrument is in adjustment the bubble will remain at the centre of its run, if not, the position of the upper bar can be slightly altered by means of the screw by which it is clamped to the bamboo until the bubble of the spirit level is brought to the centre of its run.

If the instrument is properly adjusted when first made, it seldom requires adjustment afterwards; the lower bar is permanently fixed, and with careful use the upper bar need not become displaced.

§ **60.** CLINOMETERS.—Clinometers are instruments for measuring the angle which inclined planes make with a horizontal plane. They may also be used for laying out roads and paths at a given slope.

For forest hill roads and paths a very simple clinometer, such as that shown in Fig. 21, will be sufficiently accurate for most purposes.

This clinometer consists of a wooden board *c d l k* fastened to a rod *b*, the lower end of which should be shod with iron similarly to Manson's Road-tracer (see Fig. 19, page 61).

The board is fastened to the rod so that the upper edge *c d* is at right angles to the length of the rod.

FIG. 21.

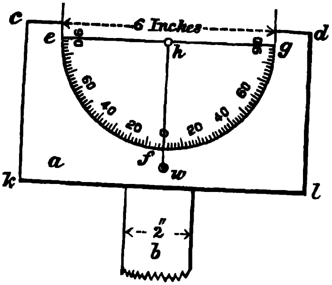


Figure 21 shows a simple form of clinometer suitable for tracing hill roads b is part of the rod to which the clinometer is securely fastened, c d l k is a rectangular board, e f g a graduated semicircle The graduations in degrees commence at f and proceed in both directions. h w is a weighted silken thread, w being the weight and h the nail (placed at the centre of the semicircle) from which the weighted thread is suspended.

A semicircle *e f g* graduated to read degrees and half degrees is pasted on to the board, with the diameter of the semicircle, *eg*, parallel to the upper edge of the board *c d*. The graduated semicircle may be engraved on the board itself. The semicircle is graduated from its centre point *f* in both directions as shown in the figure. The larger the radius of the semicircle, the more accurate will the instrument be. The radius should not be less than 3 inches, and should, if possible, be more.

A silk thread to which a weight *w* is attached is suspended from a small nail *h* driven into the board at the centre of the circle, on the circumference of which the graduations are marked. A cross staff like that described in § 52, page 52, is also required.

§ 61. METHOD OF USE.—Place the rod *b* firmly in the ground. Adjust the cross staff so that the black line on its vane is at the same height above the ground as the top edge of the board *c d* is. Move the rod *b* slightly if necessary until the weighted silk thread cuts the zero point on the graduated scale *e f g*. Then the top edge of the board *c d* will be horizontal, and the line traced by this edge will also be horizontal. The line of the road or path is traced with the upper edge *c d* of the board.

If the staff be slightly tilted until the weighted silken thread cuts the division of the graduated semicircle marked 5 degrees to the right-hand side of the zero point, the upper edge of the board *c d* will now be inclined at an angle of 5 degrees above the horizon, and the line traced by it will have an up gradient of 5 degrees. If the staff be tilted so that the weighted silk thread cuts a division of the scale to the left of the zero point, the path traced by the upper edge of the board *c d* will have the down gradient indicated by the thread where it cuts the graduated semicircle.

Care must be taken to see that the staff is upright, and that the silken thread moves quite freely and is not resting against the board. If it rests against the board it will naturally not show correctly the angle of inclination of the top of the board *c d* to the horizontal plane as it should do.

§ 62. THE MADRAS TRACING QUADRANT is another form of clinometer which has been specially adapted for laying out roads. This instrument (Fig. 22, page 67) consists of a long gun-metal or brass bar (A) fitted with sights at either end (B and C), and is fastened at the centre to an arm ending in a ball and socket joint (D) furnished with a clamping screw; the socket forms part of the cap to the staff, to which the quadrant proper is attached. A pivotted arm (E), to which a small spirit level (G) is attached, ends in a vernier index reading to minutes, and works on a vertical graduated quadrant arc (F). This quadrant is fixed to the under-surface of the bar, and the arc is turned inwards. The pivot pin is fixed one inch below the under side of the main bar, and the graduations are continued for a short distance above the zero point of the arc to allow of lines being traced down-hill as well as up. When the level tube on the index arm is parallel to the line of sight from B to C, and the bubble is in the centre of its run, the line of sight is horizontal, and the index of the vernier points to the zero point of the scale.

FIG 22.

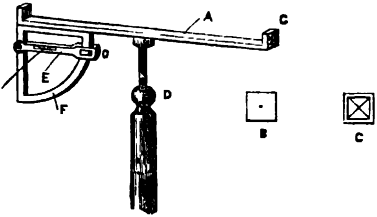


Figure 22 is a sketch of the Madras Tracing Quadrant. The long bar A *is provided with sights* B, C *at either end.* D *is a ball and socket joint furnished with a clamping screw, which allows of the instrument being turned in any direction ; E is an arm ending in a vernier which serves as an index to read the scale on the quadrant* F ; G *is a small spirit level fastened to* E ; F *is the graduated quadrant which is fastened to the lower side of the long bar* A.

The tracing quadrant is fixed to a light staff shod with iron and about 5 feet long. The bottom of the shoe is flat, so that it may rest on the surface of the ground; its base should be 1 to 1½ inches in diameter. An adjustable cross staff, similar to that used for the Abney's Level (see page 52), is required with this instrument also.

§ 63. USE OF THE INSTRUMENT.—When the staff is held vertically on the ground surface and the vernier index arm has been set to the zero point of the scale, the bubble of the level must be brought to the centre of its run by adjustment of the ball and socket joint; then the long bar (A) of the instrument will be horizontal. If the index arm be set to 2° 52′ (1 in 20), the plane of the level tube, and consequently that of the long bar, will have to be turned through the same angle in order to bring the bubble to the centre of its run, and the inclination of the line traced by the instrument will be that shown by the index on the vernier arm. The method of fixing points on the line is similar to that already described in connection with the use of Abney's Level and Manson's Road-tracer, so need not be repeated here.

SECTION V.—SETTING OUT OF ROADS AND PATHS; CURVES ON ROADS AND PATHS.

§ 64. SETTING OUT A ROAD OR PATH.—The line of pegs which has been laid down during the process of the alignment of a road or path forms usually, as has been already stated (page 44, § 47), the central line of the road or path which is to be constructed. It may be found necessary when actually constructing the road to slightly alter the line laid down, but under no circumstance should the line fixed in the alignment be materially departed from. Nor will it be necessary to do so if the alignment of the road or path has been properly made.

Before the actual construction of the road or path can be commenced, we must determine its width and general character and, if considered necessary, mark out on the ground the exact space which will be occupied by the road or path when completed. This is usually done by putting down two lines of pegs, one on either side of the centre line, to mark out the sides of the road.

For not very important or large hill roads, and for paths generally, it is usually sufficient to mark out the centre line carefully with stout pegs, in the manner described on page 44, § 47, placed fairly close to each other. The actual distance between these pegs depends entirely upon the nature of the ground traversed by the road or path. Each peg must be visible from those immediately on either side of it. The pegs driven flush with the ground should indicate the level of the surface of the road or path when made. The undergrowth should then be cleared for a distance equal to three quarters of the width of the road, so that no mistake can possibly be made as to where the centre line of the road or path is.

When the road or path is being made, the order is given to cut so many feet, the distance depending upon the width of the road or path into the hillside, and *to leave the pegs and the* *ground for one foot on either side of them untouched.* It is most necessary that the pegs should be left intact in order to ensure that the centre line is not altered, and also to allow of the earthwork or rock being measured up accurately. The strips of earth containing the pegs can be removed and the road or path completed after the rest of the work has been measured up and paid for. It is usually best to measure up and pay for the earth only first, and then when this has been done to make arrangements for removing the rock and such large trees as are in the line of the road.

In the case of an important cart-road, either in the hills or plains, after the centre line of the road has been fixed, the *side-widths* of the road should be also marked out on the ground.

The *side-width* of a road is the horizontal distance from the centre line of the road to either edge if on the surface of flat ground, or to the top of the cutting or the bottom of the embankment if the road is in cutting or on embankment.

In the case of a road across flat country the width of the road and of the side drains can be laid out directly by measurement, if the surface of the road is not to be raised. Where the road is straight, the side-widths may be laid out at considerable intervals and the intermediate widths fixed by ranging flags (see page 40, § 45).

If the road is on an embankment or in a cutting, we shall have to proceed differently.

If the surface of the ground in a direction at right angles to the length of the road is horizontal, and the road is either in embankment or cutting, it is obvious that the distance from the centre line of the road of the top of the slope of cutting or the bottom of the embankment on either side of it will be the same. Figures 34 (page 102) and 36 (page 103) illustrate this statement. G is the centre of the finished road, and G H and G K the side-widths are equal.

If however the surface of the ground, in a direction at right angles to the length of the road, is not horizontal, the side-widths on either side of the centre line will be unequal, as will be seen by reference to Figure 23.

FIG. 23.

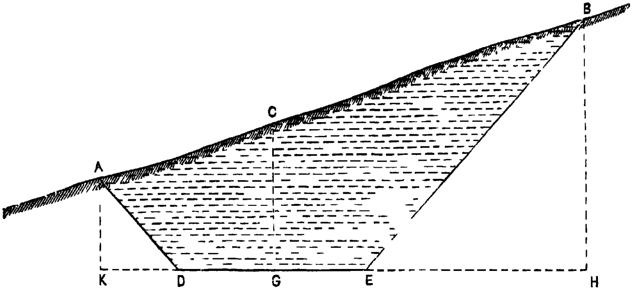


Figure 23 is a cross section of an embankment made on sloping ground to show that the side-widths G H *and* G K *are unequal. The peg on the centre line of the road fixed in the alignment is at* C. *The centre of the completed road is at* G *The pegs to mark the side-width would come at* A *and* B.

The actual height of the surface of the completed road above or below the surface of the ground at any point on it depends upon the gradients which have been fixed for the road, as will be seen by reference to Figures 34 to 38, pages 102 to 104.

In the case of an important road, a detailed survey and estimate must be prepared, in which the position of the centre line, the length, depth, and distribution of the cuttings and embankments is determined in detail. All the information with regard to the depths of the cuttings and the heights of the embankments that will be required for setting out the side-widths will be found at § 85, page 98, *et seq.*

In marking out the side-widths of the road we have to provide for the width of the road and its side-drains, and also for the slopes of the cutting or embankment, as the case may be. The space required for the road is known, and that required for the slopes of the embankment or cutting will depend upon the height of the embankment, or the depth of the cutting, and also (see § 71, page 81) upon the nature of the soil in which the road is being made. The method of marking out the side-widths of a road either in embankment or in cutting are the same. The simplest way of determining the side-widths of a road is to plot to a convenient scale the cross sections, at the different pegs which have been laid down on paper, lay off the slopes required for cutting or embankment on the paper, and scale the horizontal distance of the side-widths from the peg on the centre of the road, and then transfer these measurements to the ground. For example, suppose the road is 20 feet wide, including the side-drains, and that it is in cutting, the road surface being 10 feet below the natural surface of the ground (which has a side-long slope), and that the slope to be given to the side of the cutting is 35° —

Let A (Fig. 24) be the peg on the centre line of the road. Plot accurately the transverse slope of the ground at this point. Draw a vertical line through A, and mark off on this line a length A B 10 feet in length.

FIG. 24.

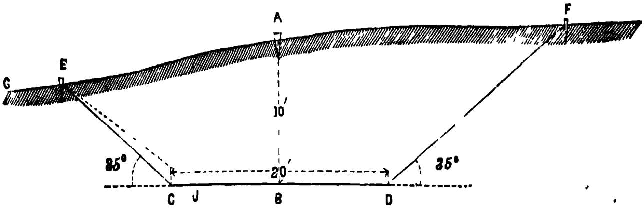


Figure 24 shows the side-widths of a road, the formation level and the width of the road being given, and the centre line laid out. In the figure CD *represents the formation bed of the road,* GH *the original surface of the ground, etc.,* CE, DF *the sides of the cutting, and* E, F *the points on the side-widths of the road; pegs are put in at* E, A, *and* F. *Scale*=$\frac{1}{10}$.

At B draw a line perpendicular to A B, and lay off distances BC, BD, 10 feet on either side of B. Then CD will represent the position and width of the road surface and drains. From

C and D draw lines making an angle of 35° with the line C D produced, and the points E and F where these lines cut the surface of the ground will be points on the side-widths of the road, and the sloping distances A F and A E marked on the ground fix the position of side-widths at the point A.

Where an embankment has to be made, its profile may be erected at intervals by planting upright sticks or bamboos in the ground at convenient intervals marking the sides of the road; the exact shape and size of the embankment is shown by cords fastened on at the required heights to show the exact position of the surface of the road and the sloping sides of the embankment.

The profile of an embankment will be that of an inverted cutting (see Fig. 24, page 71).

When the pegs to mark the centre line and side-widths of a road which is in cutting or embankment are placed in position, the depth of the cutting or height of the embankment at each of the pegs on the central line should be plainly marked. If this is done, the workmen will know at once at what depth below or height above the peg on the centre line the actual surface of the finished road will be, and can set to work at once to do what is needful. In the case of cuttings in India it is customary to leave the pegs on the centre line standing on pillars of earth so as to facilitate the measurement of the earthwork when the cutting has been dug to its full depth.

§ 65. CURVES IN ROADS.—While the road is being *aligned* no special attention is paid to the construction of proper curves on it, but when the road or path itself is being made, the necessary curves in it should be laid out carefully. Curves in hill roads and paths are usually laid out by the eye alone; the curves should follow, as far as possible, the natural features of the country in order to minimise the amount of cutting required to form the road or path. The curves are laid out on the centre line of the road, and are approximately segments of circles. When the path is carried along the side of a narrow ravine, and a sharp angle in the direction of the road, as well as a considerable increase in its length will result, if the natural features of the ground are followed too closely, a curve of not less than 50 feet radius should be laid out, either cutting through the projecting spur, or, if the road is following a valley, a bridge, or embankment with a culvert waterway, should be made.

Curves should rarely be laid out with the ruling gradient, for if this is done and the road subsequently straightened, the gradient of the new part may exceed the maximum which is allowed. The question of the gradient of the road or path along a curve must be decided locally as the road is being aligned.

When an inspection path is being made, very little attention need be devoted to the curves on it; the path should follow the natural features of the country as closely as possible. If practicable, the gradients of a road or path should be chosen, so that, if it is necessary to convert it at some future time into a road or path suitable for a higher class of traffic, good curves can be obtained. With this object in view the line where it crosses narrow streams or goes round sharp curves should be very nearly, if not quite, level, so that when gentle curves are substituted for the sharp angles, and the length of the path decreased, the gradient will not exceed the maximum allowed for the class of road which is being made.

§ 66. Curves of great exactitude are not required on ordinary forest roads or paths: they may generally be laid out either by eye or by simple measurements. For instance, suppose we have two long straight pieces of road which are to be connected by a short curved portion, a suitable curve may be obtained as follows:—

Plot the relative positions and directions of the straight portions of the roads CA, DB, (Fig. 25) to any convenient scale on paper.

FIG. 25.

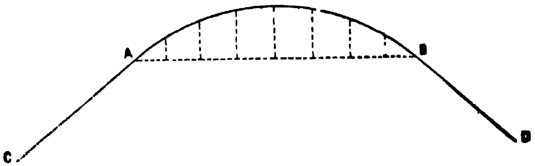


Figure 25 shows how a curve may be laid out on paper so as to join the ends of two straight portions of a road CA, DB.

Join AB and draw a suitable curve joining the two straight lines on paper: the straight portions of the road should be as nearly as possible tangents to the curve at A and B. Mark off a number of equidistant points on the curve, and from them drop perpendiculars on to the line AB and scale off these distances. Transfer the points thus obtained on the chord AB to the ground, setting out AB accurately straight and marking the points on it and then set off the lengths of the respective perpendiculars to the curve at these points, the points thus obtained on the curve can be joined by eye.

It is sometimes necessary to construct a curve in order to avoid locally a bad piece of ground without materially changing the general direction of the road; this may be done by setting out a double reverse curve as shown in Fig. 26. This curve consists really of 3 arcs of the same circle joined together.

FIG 26.

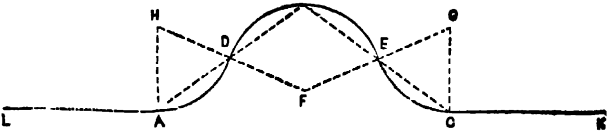


Figure 26 shows a method of constructing a double S curve to avoid a small difficulty without materially altering the direction of the road. The curve is made up of arcs of circles AD, DBE, EC, *described from* H, F, *and* G *as centres.* LA, CK *is the general direction of the road. In the figure the radii of the circles have been made too short, and consequently the resulting curves are too sharp.*

The distance across the bad ground is divided into two equal parts, and opposite this point at right angles to AC a point B is marked for the position of the road clear of the bad ground. Join BA and BC, and find the centre points D and E of each line. From A and C at each end of the intended gap erect perpendiculars AH and CG. Bisect AD and EC each by a straight line at right angles, let these straight lines cut the perpendiculars from A and C at H and G respectively, then H and G are the centres of the arcs, drawn tangential to LA and KC, and passing through the mid points D and E. Join HD and GE, produce them to intersect at F, which is the centre of the arc, from D to E passing through B. If the curves thus formed have too small a radius, the points A and C must be moved further from each other, till the distance apart permits the use of the minimum radius.

Curves in roads should be made as gentle as possible. If possible without going to great expense, no curve on a cart-road should have less than a radius of 60 feet to the centre line of the roadway.[1] Where the direction of the road is reversed the radius of the curve at the turn should be as long as the nature of the ground, with due regard to depth of cutting and height of retaining wall, will permit. The minimum curves should have radii of 50 to 80 feet to the centre of the road, according to the number of degrees in the angle, at the centre of the circle subtended by the curve itself.[1]

If the curve of a road or zig-zag is very sharp, the road should be made considerably wider at the corner so as to allow of laden carts, especially those used for the carriage of logs projecting some distance beyond the end of the cart, to pass round them without knocking against the hillside.

[1] "Treatise on Mountain Roads," by General H. St. Clair Wilkins, pp. 110, 120

SECTION VI.—THE CONSTRUCTION OF ROADS.

§ 67. The estimate for the construction of the road having been made and sanctioned, the actual line which the road or path is to follow should be selected, the side-widths marked out if that is necessary, and the actual construction of the road may then be commenced.

The construction of the road includes making cuttings or embankments in order to obtain the requisite gradients for the road; constructing bridges and culverts to carry off the drainage of the country (see Part IV, page 109, *et seq.*); giving the correct shape to the surface of the road (see page 7, *et seq.*); building revetment walls for retaining the earth on steep slopes (see page 18, *et seq*); making suitable provision for the drainage of the road surface (see page 11, *et seq*); and, if necessary, metalling the whole or a portion of the surface of the road (see page 21, *et seq.*).

These works may be done by daily labour or at contract rates. The construction of roads entirely by daily labour is objectionable, because, unless the workmen are properly supervised, they do as little as they can; on the other hand, in many places it is difficult to get men really qualified to come forward and take up the work on contract. It is best, if practicable, to do the rough work, such as making cuttings and embankments and blasting, by contract, and to finish the road by daily labour, as the workmen employed on daily labour can then be thoroughly controlled, supervised, and trained to do the work properly. If the whole of the work is done on contract, it will probably be badly done, because the workmen employed do not know how to do the work properly, and the contractors will not or are not able to show them how to do it.

In India roads should be made as soon after the rains as practicable, while the earth is still soft and easy to dig; and the earth will settle and harden considerably before the next rainy season sets in.

§ 68. As a rule, for the construction of inspection and bridle-paths in the hills and of fair-weather roads in the plains, no detailed estimates are required. It will usually be sufficient to lay out the centre line of the path or road and get the work done by daily labour or by contract at a fixed rate per mile or per 100 feet. The rate paid will vary from place to place along the path according to the difficulties met with.

For important cart-roads, involving the excavation of deep cuttings and the formation of high embankments and the construction of culverts, bridges, and revetment walls, careful estimates (see page 98, *et seq.*) should be prepared before the work is commenced. The same remark applies to the construction of sledge-roads and of important bridle-paths.

The work may be done on contract at fixed rates per unit volume of earth and rock removed. The alignment pegs should be left undisturbed on the site of a cutting, where they will stand on truncated cones of earth about 1½ feet across on the original surface of the ground in order to allow of the volume of the earth and rock removed being correctly measured after excavation.

§ 69. EARTHWORK includes the excavation of earth and loose, friable rock, such as can be removed with a pick-axe, and the deposition of earth to form embankments.

Before the earthwork is commenced, the area of bank cutting should be cleared of all vegetation, and any trees should be dug up by the roots (not cut off flush with the ground and the roots left in the ground); and all old stumps should be removed. It is much easier to dig up a tree by the roots than to fell it first and dig out the roots afterwards.

§ 70. The principal tools required for road-making are Indian hoes (*phaorwas* or *mamoatis*), spades, shovels, picks, heavy hammers, crowbars, wheel-barrows, baskets; and for blasting, jumpers and a tamping rod.

Where the soil is loose, the same tool which detaches the soil may be used to raise it and put it into the vehicle in which it is removed. A *spade*, *shovel*, or large-bladed hoe (*phaorwa*) may be used for this purpose.

Where the soil is stiff and firm, it must be broken up before it can be removed by any of the above-named tools, and a *pick* is used for this purpose.

The spade and shovel are European tools. The spade usually has a rectangular blade and a short handle, and is very well suited for digging in soft earth which is free from stones. If spades are used, the workman's foot must be protected by a boot or piece of leather. A shovel may or may not have a heart-shaped blade. The sides of the blade, if rectangular, are slightly bent up, to allow of its holding more earth. The shovel is much used for throwing loosened earth into baskets, wheelbarrows, trucks, carts, or elsewhere.

A pick is made of iron of the shape shown in Fig. 27, steel points being welded on to either arm; the arms should be equally balanced.

The pick should measure about 18 to 20 inches from point to point for rock work, and should weigh about 8 lbs. For hard earth picks may measure 2 feet from point to point and weigh 12 lbs.; if they are made too heavy, they fatigue the workmen.

The socket into which the handle fits should taper slightly and be 1¾ to 2 inches in diameter, and should be sufficiently deep to admit of the latter being fitted securely into the tool: the distance from D to E should be 3½ or 4 inches. Picks require to be sharpened and repaired frequently.

FIG. 27.

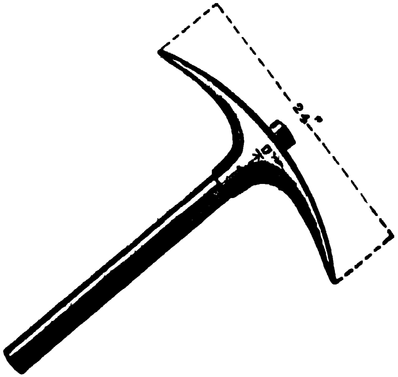


Figure 27 is a sketch of a pick. The socket DE *into which the handle fits should be from 3½ to 4 inches deep.*

Small shallow baskets usually carried on the head are most universally used for carrying earth in India. Wheel-barrows may be used for removing earth when the distance over which it has to be carried is short, when the ground is inaccessible to carts or when the quantity of earth to be removed is small. Shallow wheel-barrows,[1] (about 6 inches deep) with their sides splayed open to make an angle of 45° with the bottom, so that their contents may be discharged easily, are best suited for the removal of earth.

The frame of the barrow is constructed by morticing three cross bars into the two side rails forming the handles and coming close together at the other ends where the wheel is carried between them. The box of the wheel-barrow may be made separately, and may be fixed by screw bolts and nuts to the frame. One frame will last as long as several boxes. The axle

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"The Roorkee Treatise on Civil Engineering in India," 3rd edition, 1878, Vol. I, page 242, § 215, *et seq.*

of the wheel is inserted in iron eyes fixed by screw bolts to the side rails of the frame. In the Ganges Canal Works the wheel-barrows were used with shoulder straps attached to the handles. The wheel-barrows should run on planks 3 inches thick and 9 to 11 inches wide placed so as to form a continuous track; these boards may be propped up by wooden blocks to obtain a suitable gradient.

The gradient of the wheeling track should be as level as possible, and should never exceed 1 in 12.

It has been found that two or three men according to the nature of the soil, with picks and shovels are required to dig, in order to keep one wheel-barrow employed; one shovel takes as long to fill in one cubic foot of earth as a wheeler will take to go and return 100 or 120 yards, 1 foot of rise being equivalent to 6 feet on the level; a native workman will lift 125 cubic feet of earth and place it in a wheel-barrow or basket in one day.[1]

For ordinary works where earth has only to be taken short distances, baskets carried on men or donkeys will generally be found most economical, as they are the ordinary carrying implements of the native workman, and can be obtained everywhere at a very small cost, whereas wheel-barrows are expensive to make, require repairs from time to time, and the natives have to be taught how to use them.

The cost of the earthwork varies in different localities and depends upon the cost of labour, the nature of the soil, the distance which the earth has to be carried, as well as the depth of the cutting or height of the embankment. The cost of earthwork on the upper part of the Ganges Canal was R2 to R2-8 per 1,000 cubic feet, while in the Cawnpore district it was R1-8 per 1,000 cubic feet only. In Assam the rates paid for earthwork vary from R4 per 1,000 cubic feet and upwards. The only implements used for carrying and digging are the basket and the Indian hoe. In Madras, as a rule, R3-8 per 1,000 cubic feet is paid for sand, R4-12 for clay and hard earth, and R6 for very hard soil for digging, and 5 to 10 per cent. is added to these rates, according to locality, for every furlong of carriage.

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[1] "The Roorkee Treatise on Civil Engineering," 3rd edition, Vol. I, page 244.

§ **71.** CUTTINGS AND EMBANKMENTS.—The slopes given to the cuttings and embankments should stand unsupported, and vary with the stability of the soil; this depends partly upon the friction, and partly upon the adhesion of the component grains.

The slope at which any soil will rest is called the *natural slope* for the soil in question, and the actual angle which this slope makes with the horizon, is called the *angle of repose* for that soil. The natural slope is usually expressed by the ratio of its horizontal breadth to its vertical height.

The following table[1] gives the angles of repose and natural slopes of some of the more common soils; the gentler of the two slopes given in each class of soil is the slope which should be given to the slopes of embankments; the steeper applies to the slopes of cuttings. In case of doubt the angle of repose for any soil can be found by direct experiment:—

Nature of soil.	Angle of repose in degrees.	NATURAL SLOPE.	
		Horizontal distance.	Vertical distance.
Dry sand, clay and mixed earth	37° to 21°	1·33 to 2·63	1 1
Damp clay . . .	45°	1	1
Wet clay . . .	17° to 14°	3·23 to 4	1 1
Shingle and gravel . .	48° to 35°	0·9 to 1·43	1 1

The most common slope given to earth is 1½ : 1, and if the depth of the cutting or height of the embankment be greater than 35 feet, 2 : 1. Certain clays though hard when first exposed are liable to disintegrate on exposure and become less stable, when flat slopes of 2½ to 1 up to 4½ to 1 may have to be adopted. In Assam embankments are generally given a slope of 2 · 1 and cuttings a slope of 1 : 1.

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[1] "The Roorkee Treatise on Civil Engineering," 3rd edition, 1877, Vol. I, page 222, § 191.

The slopes of the sides of cuttings may be made much steeper than those of embankments in the same soil. If the soil is stiff they can be made fairly steep, so long as they are not cut away by the dash of the rain on them. The steeper the slopes of the cuttings the less will be the excavation required to make a road of a given width. If however the slopes of the cuttings are made too steep, slips of earth from them blocking the road partly or entirely will be of frequent occurrence.

§ 72. FORMATION OF SIDE SLOPES OF CUTTINGS.—The excavation of cuttings and the formation of embankments may be commenced as soon as the side-widths have been set out on the ground. The workmen should be instructed what slopes are to be given to them, and may be provided with *bevel plumb-rules* to lay out the actual slopes required. A *bevel plumb-rule* or *battering rule* consists of three strips of wood, 2 inches wide and 1 inch thick, as shown in Fig. 28, nailed together to form a right angle at B, the ratio of BC to CA being that of the slope required; the side AC will represent the slope of the

FIG. 28

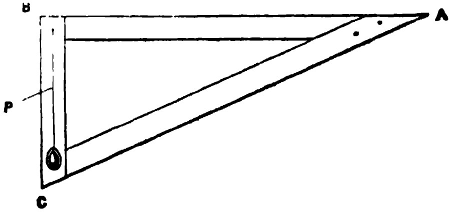

Figure 28 is an elevation of a bevel plumb-rule for laying out the slopes of a cutting. The angle at B *is a right angle; a plummet* P *is fastened to the side* BC; *a line parallel to the outer edge of* BC *is marked down the centre of the batten, and when the string coincides with this line the side* BC *is vertical. The ratio between* BC *and* CA *is made that of the slope of the cutting.*

cutting when the side BC is held vertically; a plumb line is attached to the side BC for this purpose; the side AC should be at least 3 feet long.

The workmen begin digging a hole near the side-width and make the slope of the cutting gentler than that ultimately required. The point C of the bevel plumb-rule is introduced into this hole with side AC along the slope of the cutting; if the plummet coincide with the line on the rule, the slope is correct, if not more earth is dug away until the right slope is made, and this is continued on to the bottom of the cutting. A cutting of considerable depth is generally dug out in steps or stages of 7 or 8 feet in height, and each stage has its barrow roads, cart-roads, or tramways. To preserve a sound formation surface, or road bed, the last 12 to 24 inches depth of earth is not dug out until the whole of the rest has been excavated, then the remainder is carefully dug away, leaving an undamaged formation surface correctly profiled.

§ 73. DETERMINATION OF THE ACTUAL GRADIENT OF ANY PORTION OF A ROAD.—In excavating cuttings, the road must be given its correct gradient between the centre line pegs, and steps must be taken to ensure that the full depth of earth is removed. If we insist on the original pegs of the centre line of the road being left on pillars of earth, we can at once see if the cutting has been excavated to its full depth or not.

There are many ways of testing whether the gradient of the road in the cutting is correct or not.

An Abney's Level may be set to the gradient which the road should have, and the cross staff, properly adjusted, placed at any point on the centre line of the road; then if we read on to the cross staff the horizontal hair of the instrument must either exactly cut the black line on the vane of the cross staff (see Fig. 15, page 52), or else cut the staff either above or below it. If the horizontal hair of the Abney's Level cut the sight vane of the cross staff below the black line on it, the distance between this point and the black line on the sight vane will give the depth to be dug out to obtain the required gradient.

Or a hole may be dug out where the cross staff is held, and a peg be driven down in the bottom of the hole until the black line on the sight vane standing on the peg is correctly in the line of sight of the level; the top of the peg then shows the depth of excavation.

If the hair of the level, when the level is set to the required gradient, cuts the cross staff above the black line on the vane, it shows that the cutting has been dug too deep by the distance between the point where the cross staff is cut and the black line on its vane.

The gradient may be also fixed by the instrument shown in Fig. 29, which consists of a straight edge AB, to the middle point of which is fixed an upright CD at right angles to it. This upright is furnished with a plumb line F similar to that attached to the bevel plumb-rule. Near the end B is a vertical bevelled sliding bar fitted in an under cut groove, and fixed at any height by a thumb screw.

FIG. 29.

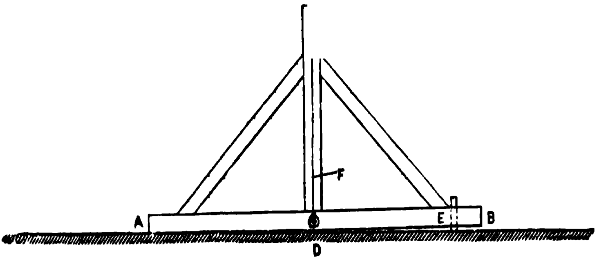

Figure 29 is an elevation of a Mason's Level or trussed straight edge, showing its use in setting out the gradient of a cart-road at intermediate points between centre line pegs. Scale $\frac{1}{12}$.

When the upright CD is vertical (*i.e.*, when the plumb line coincides with the line marked on the upright, see volume I, page 174, parallel to its sides, and consequently perpendicular to

AB) the batten AB is horizontal. The sliding bar E can be made to project any required distance below the lower surface of the batten. If the peg be made to project 1 inch and the distance from A to E is 5 feet (60 inches), then if the instrument is held so that AB is horizontal then the slope of the line joining the bottom of the peg to A will be measured by the ratio of the length of sliding bar projecting, in this case 1 inch, to the distance AE, that is, 60 inches, or the line from A to the bottom of the sliding bar E will have a gradient of 1 in 60. By altering the length of sliding bar projecting from the under surface of the batten AB we can make the gradient of the line from A to the bottom of the sliding bar anything we like.

The gradient of a road between any two pegs fixed in the alignment may be set out by means of *boning staves.* Boning staves are rods of equal length, with cross bars accurately fixed on at one end (see Fig. 31). Three staves, 4 to 5 feet long, with squared lower ends, two of them fitted with stout iron spikes, are required. The two spiked staves are planted upright at two adjacent centre line pegs, and the third stave is placed upright on the ground surface, or on an intermediate peg driven in till the line of sight from the top of one fixed boning stave to the other exactly coincides with the upper surface of the cross bar on the movable stave.

FIG. 31.

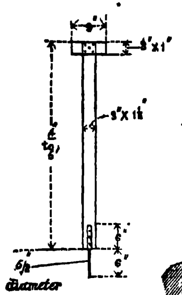

FIG. 30.

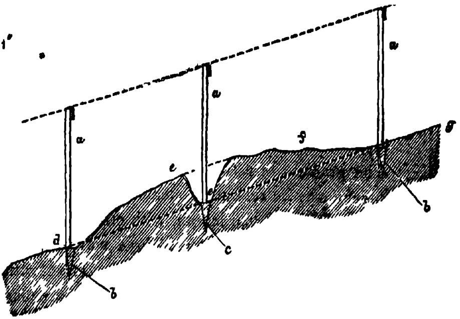

Figure 31 is a boning stave, while Fig. 30 shows how boning staves are used to lay out a road between two fixed pegs a, a, a are the boning staves. b, b the pegs laid down in the alignment of the road, c is one of the intermediate pegs fixed by the staves. d, e, f show the original surface of the ground. the dotted line d g indicates the completed formation surface of the road.

§ 74. In excavating cuttings time may be saved by digging and removing the earth in the ordinary way until a depth of 6 or 7 feet is attained; the sides are kept at the proper slope and the face or front is kept nearly perpendicular. A portion or all of the face is then undermined about 1 feet above the bottom of the cutting, and the unsupported mass of earth falls down of its own weight, or is dislodged by large wedges driven into the ground at a distance of 3 or 4 feet back from the edge of the face, water may be poured down the wedge holes if necessary.

§ 75. CONSTRUCTION OF EMBANKMENTS.—The best materials for the construction of embankments are stones, shingle, or gravel: fine dry non-adherent sand, wet clay, vegetable mould and mud are quite unfit for such work.

Earth is very commonly used, and forms good embankments after it has settled properly. If pure sand is used the side slopes must be protected against the denuding action of the rain by turf.

Embankments may be formed in three ways :—

(1) In one layer.
(2) In two or more thick layers.
(3) In a number of thin layers.

The first of these methods is the quickest and cheapest, and is consequently the one most frequently used : the embankment is formed to its full height, and progresses by throwing earth down at the end of the completed portion. The earth is not artificially consolidated in any way, and consequently *settles* (*i.e.*, shrinks or occupies smaller space) more than if deposited in layers and rammed ; it also takes a longer time to settle completely. This is a very good method of forming an embankment if the earth is allowed to settle thoroughly before the roadway is finally constructed.

In the second method the embankment is first raised to $\frac{1}{2}$ or $\frac{1}{3}$ its full height, and this layer is allowed to settle before the remaining ones are added. This method is seldom used, as it involves much additional labour and time. The method of making the embankment of a number of thin layers ensures the greatest density and stability, but the work proceeds more slowly and is more expensive ; the layers should be from 6 to 12 inches in thickness, and should be concave in section. This method is only used in special cases where great solidity is required, such as in the construction of dams to retain water, or filling in behind retaining walls, etc.

When an important embankment is made on ground with a sidelong slope, it is advisable to cut out the hillside in steps whose surface is at right angles to the slope of the side of the bank. The toe of the slope may also be supported by a dry stone well sunk 4 to 6 feet in the ground, in order to give it a firm footing.

FIG. 32.

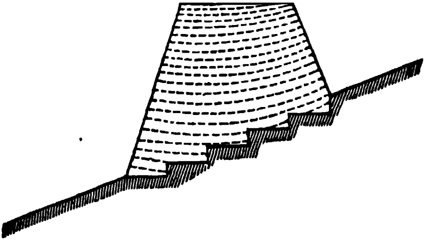

Figure 32 is the section of an embankment showing how its base should be stepped into the slope on sidelong ground.

All made earth is liable to settle, *i.e.*, to contract in volume and occupy a smaller space than when first put down. The amount of shrinkage depends upon the nature of the soil, the height of the work, and manner of deposition. In calculating the quantity of earth required for embankments, an additional allowance to the actual volume of the required embankment of $\frac{1}{8}$ for sandy soil and $\frac{1}{12}$ for gravelly earth should be made. The slopes of cuttings and banks should be protected from the weather by turf or by the planting of *dhub* grass (*Cynodon dactylon*). Great care should be taken to prevent rain from sinking into new embankments, as its entrance will soften the lower layers of earth and cause unequal settlement. The top of a new embankment should be made slightly higher at the centre than at the side, in order to allow the rain falling on it to run off.

§ 76. When an embankment is made across marshy ground the wet soil must be thoroughly drained by a longitudinal drain on each side of the intended roadway, and cross drains connecting the two at frequent intervals, according to requirements. Where it is difficult to dig and keep open a ditch owing to soft soil, quicksand, or bog, an effective drain may be made of brushwood gabions, which are hollow cylinders of brushwood interwoven between stout stakes (eight in number) placed equidistant and in a circle. In making the gabions the stakes are planted upright in the ground, and the brushwood is woven inside and outside alternate stakes. These gabions are placed in line on the ground and are sunk by undermining. Effective drains may also be made of the slabs sawn off squared logs; by alternating the position of the but joints on the slabs the slab-box drains can be made continuous of any length. When the wet soil is thoroughly drained the surface to carry the roadway should be strengthened by two or three layers, of fascines, or tied up bundles of grass, brushwood, put down to serve as a mattress on which the embankment may be carried; the fascines should cross joints in successive layers and be firmly packed together. Bark of trees, turf-sods, reeds, coarse grass may be placed on the fascine mattress to receive the earth of the roadway.

§ 77. HEIGHT OF EMBANKMENTS.—In low-lying flat country, in order to keep the road surface above the level of ordinary floods, the height of the roadway embankment must be at least 2 feet above the level of the highest ordinary flood ascertained by careful enquiry and from the observation of flood-marks on trees and buildings in the neighbourhood.

These embankments may intercept the surface drainage of the country, and ample provision of waterway must be made through the embankments by bridges and culverts. Where the rainfall is heavy the maximum quantity of water which may have to pass through the embankment must be calculated and provided for. It is often difficult to do this owing to the acreage of the catchment area not being accurately known, and also to the occasional occurrence of unusually high floods. Some part of the embankment may be made lower than the rest in order to allow of the water brought down by floods passing over it; if this is done, the sides of the road on this portion should be specially protected against denudation.

Where the rainfall is scanty and floods uncommon, the whole roadway may be level with the surface of the ground. The only inconvenience resulting from this procedure will be the temporary stoppage of traffic when heavy rain falls.

§ 78. BALANCE OF CUTTINGS AND EMBANKMENTS.—It is important that the amounts of cuttings and embankment should be made to balance each other as far as practicable, as, if the former are too great, the extra quantity of earth will have to be disposed of in *spoil banks*, and if too small, earth will have to be dug from side cuttings, or *borrow-pits*, to make some of the embankments. As far as possible, earth from a cutting is used to form an adjacent embankment, but in this connection the distance earth has to be carried must be considered. It may be cheaper to get earth from side cuttings than to bring it from the nearest cutting. The volumes of the cutting and embankments can be equalized to a great extent by raising or lowering the gradients of the road.

If earth is excavated from along the sides of the road to form the embankments, it should be dug out in a series of broad shallow trenches (*borrow-pits*), separated by banks of untouched earth to prevent damage from the scouring action of running water during the rains.

In India, where land and labour are cheap, it is usually more economical to make an embankment from side cuttings or *borrow-pits* close at hand than to bring the earth from a distant cutting.

If cuttings and embankments are paid for at the same rate, and one is close to the other, so that earth from one can be carried to the other, only one should be paid for. If they are paid for at unequal rates, the higher rates should be paid.

§ 79. ROCK BLASTING.—When rock is too hard to be removed by a pick it must be blasted. Coarse-grained gunpowder is generally used for this purpose; dynamite and blasting gelatine are also used, but require careful handling and are dangerous in the hands of inexperienced workmen.

The best quality of blasting powder that can be obtained should be used. The best proportion of nitre—the most valuable ingredient—is 75 per cent. Experience has shown that it is false economy to use a cheap and necessarily inferior powder for blasting purposes. The addition of sawdust to blasting powder does not, as is commonly supposed, increase its efficiency.

The advantages of a superior powder are[1]—

(1) Small quantities go further, and consequently the stock required for consumption would be easier to stow away and carry.

(2) A greater effect is produced with a smaller amount of labour, and what is sometimes of consequence of time in boring holes.

(3) By occupying a smaller space in the bottom of the hole an increased resistance in the tamping would be obtained by its greater proportionate extent.

(4) The better qualities of powders are much less subject to deterioration from keeping than ordinary blasting powders.

§ **80.** BLASTING WITH GUNPOWDER.—Hard rock is removed by boring holes in it, placing charges of powder in the holes, filling them up with clay or such other material as may be available, and igniting the powder; the powder expands in changing from a solid to a gaseous state, and in expanding splits off pieces of the rock in which it is embedded.

The implements used in blasting rock are—

(1) A jumper or a drill bar.
(2) A scraper or spoon.
(3) A tamping bar.
(4) A needle.

The *jumper* is a bar of carbon steel of good tough quality and chisel pointed at both ends. The bar is circular in section usually 1¼ to 2½ inches, the chisel edge being widened out about ½ to ¾ of an inch, and 6 to 7 feet long. A drill bar is a shorter bar 3½ to 4 feet long, of the same quality of steel, and is pointed at one end only; one man holds the bar while drilling, the second strikes the upper end with a sledge hammer; a slight twist is given to the bar between the blows.

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[1] "Rudimentary Treatise on the Blasting and Quarrying of Stone for Building and other purposes," by General Sir John Fox Burrgoyne. London: John Weale, 1849.

The *spoon* is an iron rod, one end of which is beaten out and curved so as to form a groove in the shape of a half hollow cylinder; its lower end is closed with a semi-circular disc.

The *tamping* bar is a heavy, slightly tapering, brass or copper rod; the diameter at its larger end is a little less than that of the hole to be bored. If fuses are not used to ignite the powder the tamping bar should have a groove along one side, so that the bar may be used when the needle is in the hole. Tamping rods are made of copper or of brass in preference to iron, as these metals do not give off sparks when struck upon hard substances.

The *priming needle* is only necessary when a fuse cord is not used. It consists of a thin metal rod with a loop at one end which serves as a handle, the other end is pointed. The priming needle may be made of iron coated with brass; copper should only be used when brass is not obtainable, as it is too soft. The needle should be well greased before being put into the hole, to allow of its being easily withdrawn when required.

A hole in the rock is bored with the jumper, which is usually worked by two men, one of whom sits down on the rock and holds the lower end of the bar, and guides it so as to strike fair into the hole, while the other stands upright, raises the jumper about a foot above the surface of the rock and drives it forcibly home. A little water is occasionally poured into the hole to convert the dust into mud and to keep the jumper cool.

The jumper is twisted round slightly after each stroke. The dust or mud formed is removed from time to time with the spoon. When the hole has been bored to a sufficient depth it is cleaned out and dried, and the charge of powder placed in position. A piece of fuse cord is placed in the hole so as to communicate with the powder; its upper end is cut off so as to leave 2 or 3 inches above the mouth of the hole. The hole is then gradually filled with *tamping;* that first put in is gently pressed over the wadding which should be placed above the powder, more tamping is added and rammed home with the tamping bar, and this process is continued until the hole is completely filled. All that then remains to be done is to set fire to the fuse and retire quickly to a safe distance from the hole.

If a fuse is not used, a priming needle is placed in the blast hole in communication with the powder until it is tamped; the needle is then withdrawn and the hole filled with fine powder. The charge is fired by means of a slow match made of paper or linen soaked in a strong solution of nitre (potassium nitrate) or gunpowder, and arranged so as to give the person lighting it time to retreat before the powder explodes.

The best *tamping material* is finely divided clay (burnt if practicable); the earth from white-ant (*Termes* sp.) hills makes good tamping; if neither of these are available, broken brick, chips of stone, earth or wet sand can be used: dry sand is the worst tamping material, as it offers very little resistance to the explosive force of the powder. If broken brick is used it should be reduced to small pieces and dust, and is improved by being lightly moistened with water when it is being rammed home. Some kinds of rotten stone are nearly as good as clay or moistened broken brick, but as a rule chips of stone do not make good tamping, and should never be used as they are likely to strike fire (like flint does) when rammed home.

A good blast should produce a smothered report, and a mass of rock should be lifted and thoroughly fractured without being forcibly projected and broken into small pieces. The useful effect of a blast depends a great deal upon the judicious selection of the holes.

§ 81. *The line of least resistance* to the explosive force of the powder is that line by which the powder will find the least opposition to its passage into the air; it is generally the shortest distance from the seat of the charge to the surface of the rock. In distinctly stratified rocks, however, the line of least resistance will be in the direction of the layers of stratification. When a rock is stratified or jointed, holes bored parallel to the strata or joints will produce much greater effect than the usual vertical ones. The effect of the powder will be greatest when the axis of the hole is at right angles to the line of least resistance, and least when it coincides with that line. It is wrong to bore the holes across crake in the rock, as if this is done the powder will blow out of them. The depth of the hole should not exceed one-half the line of least resistance.

The ordinary rule for ascertaining the weight of powder to be used for blasting rock of ordinary tenacity is—

The weight of powder in lbs. =

$$\frac{(\text{line of least resistance in feet})^2}{32}$$

The figure given by this formula should in every case be qualified by the results obtained, as different kinds of rock offer different resistances to the explosive force of the powder.

In Assam the usual practice is to fill one-third of the hole with powder and the remaining two-thirds with good tamping material, such as clay or small stones.

The following table [1] which shows the depth of hole required for given charges of powder was compiled by Major-General Sir Charles Pasley, K.C.B.:—

Diameter of the hole.	Powder in 1 inch of hole.		Powder in 1 foot of hole.		Depth of hole required to contain 1 ℔ of powder.
Inches.	lbs.	oz.	lbs.	oz.	Inches.
1	0	0·419	0	5·028	38·197
1½	0	0·942	0	11·304	16·976
2	0	1·676	1	4·112	9·549
2½	0	2·618	1	15·416	6·112
3	0	3·770	2	13·240	4·244

A fuse should always be used in preference to a train of powder. Bickford's fuse is considered to be the best which can be obtained. It consists of a cylinder of gunpowder or other explosive compound, enclosed within a hempen cord which is first twisted and then overlaid with another cord to strengthen the casing thus formed, and then varnished to preserve the contents from injury by moisture, and finally covered with whitening or other suitable matter to prevent the varnish from adhering. This fuse is efficient in damp situations, and a special quality is prepared expressly for use under water. Miss-fires scarcely ever occur if this fuse is used, and it is a very great protection against accidents. The ordinary fuse burns at the rate of 2 or 3 feet per minute.

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[1] See "Roads and Railroads," by W. M. Gillespie, page 163, 10th edition. A. S. Barnes & Co., New York and Chicago.

If the holes are wet, the charge may be placed in a waterproof bag and the fuse tied closely in its mouth. The bag is then pushed home to the bottom of the hole, which is then tamped and fired in the usual way.

The depth of hole which can be bored in one day depends upon the hardness of the rock. On the Bamsu sledge road in hard quartzite only 8 to 12 inches of hole, 3 inches in circumference, was bored by two men in one day, while on the upper portion of the sledge road in micaceous schist, as much as 72 inches was bored by two men in a day.

The blasting work on the Bamsu sledge road was paid for at a fixed rate per foot of hole bored, the rate varying with the difficulty of boring the holes, the powder and fuse being supplied departmentally.

§ 82. BLASTING WITH DYNAMITE.—Dynamite is composed of nitro-glycerine and an absorbent earth, and is very much more effective than gunpowder for breaking up large stones and roots of trees. It is generally supposed to be much more dangerous than the former substance, but many experts state that, if carefully used, this is not the case. It freezes at 40° F., and explodes spontaneously at a temperature of 350° F.; in a frozen state it is extremely dangerous, and consequently it is not suitable for use at high elevations in the Himalayas. It is especially valuable for blasting under water, as holes of smaller bore are required, and only loose tamping, such as sand or water, is necessary. In some cases dynamite may be simply laid on the surface of the stone to be broken and covered with sand or clay, but in this case a large quantity of dynamite must be used. Dynamite is exploded by means of a detonating fuse.

§ 83. The following information regarding the storage and use of dynamite for blasting purposes was communicated by Mr. H. Slade, Deputy Conservator of Forests, Western Circle, Upper Burma.

Dynamite is sold in boxes, each box containing 50 lbs. There are 10 packets in each box, and each packet contains 32 cartridges, so that a cartridge contains 2 or 3 ounces of dynamite.

Dynamite cartridges must always be exploded by means of detonators. The detonators must always be kept perfectly separate from the dynamite itself. Dynamite should also be kept, as much as possible, away from contact with iron work, especially in stormy weather.

It should not be exposed to the midday sun for long, as if heated above 157° F., it is liable to explode by concussion , nor must it be exposed to temperatures lower than 40° F., because if cooled down below that temperature it also explodes very easily by concussion.

The boxes of dynamite may be carried to the seat of operations in carts by coolies or on elephants , but in any case the boxes should be protected from the sun in the middle of the day.

The boxes containing dynamite should be stored in a shed at a considerable distance from any dwelling-house, and in a locality which is not exposed to extremes of temperature. The shed may be banked over with earth to keep its temperature more uniform. No iron or detonators should be kept in the shed in which the dynamite is stored.

METHOD OF USING DYNAMITE.—The method of using dynamite for blasting rocks in connection with the preparation of streams for floating purposes is as follows. If a large irregular boulder of hard rock, 12 feet in diameter and 15 feet high, is to be removed, a hole about 2½ inches in diameter and 3 feet deep is bored in the centre of the rock. Four coolies will take three or four hours to make such a hole. All irregular projections are bored at the same time, the holes in the projecting pieces being made 1½ inches in diameter and 1 foot deep. Twelve cartridges are placed in the central hole, tied up in bundles so as to fit the bore of the hole. The bundles are placed one above the other, and a detonator with a fuse attached, is fastened to the top bundle. The fuse is led out of the blast hole, about 6 inches of fuse projecting beyond the hole. The hole is then filled with earth, well moistened in order to make it bind, and small stones rammed tightly together. A large boulder or a heap of stones is usually placed over the hole, this has the same effect as deepening the hole itself.

The small holes are similarly charged, the amount of dynamite placed in them being proportional to the amount of rock to be removed.

All the projecting ends of the fuses are lit simultaneously, the smaller holes explode first and reduce the boulder to a more or less regular shape, while the main charge splits the whole of the boulder into fragments.

If the rock is soft the effect of the dynamite is very much less, and the boulder will have to be blasted two or three times before it is entirely removed.

Small boulders may be broken up by exploding a detonator, or a detonator and a small charge of dynamite, on its upper surface without boring any hole, but such a procedure is very wasteful.

Rocks under water can be blasted by dynamite. If the rock is only a little below the surface of the water, the hole is bored with the ordinary tools, but the depth of the holes should be decreased and their number increased. The detonators are attached to the top bundle of dynamite cartridges and fastened to a length of wire which, connected with a galvanic battery, an electric spark causes the charge to explode.

§ 84. BLASTING GELATINE.—This is a compound of nitroglycerine and gun-cotton (itself a powerful blasting agent), the latter being in a much smaller proportion than the former. The result is that blasting gelatine is 50 per cent. more powerful than dynamite. It can be kept in water without exuding. Like dynamite, it is very dangerous in a frozen state. It is used exactly in the same way as dynamite. For both dynamite and blasting gelatine insensibility to shock is claimed, but it is nevertheless a fact that cartridges which have missed fire in bore-holes have afterwards exploded when new holes have been jumped near them. Consequently there is danger in firing several charges at once, because it is very easy to imagine all of them to have exploded when it is not really the case. Both dynamite and blasting gelatine will act when merely placed upon a rock surface, but they do more work when placed in bore-holes.

SECTION VII.—MENSURATION OF EARTHWORK; ESTIMATES.

§ 85. MENSURATION OF EARTHWORK.—A road practically consists longitudinally of a horizontal or inclined plane, or a series of such planes of a certain width, to which a slightly convex shape is given with a view to allowing the rain which falls on it to run off into the side drains as quickly as possible.

In order to obtain this profile for the road surface it is necessary either—

(1) To make a cutting in the ground;

(2) To make an embankment on the original ground surface; or

(3) To form the road partly by cutting and partly by embankment.

After the direction of an important road has been determined, before any estimate of the probable cost of its construction can be made, it is necessary to calculate the volume of earth and stone which will have to be removed and deposited, as well as the cost of the bridges, culverts, revetment walls, drains and metalling.

In the case of hill-paths it is rarely necessary to calculate very accurately the actual volume of earth and stone which has to be removed. When the path is cut entirely out of the hillside, the volume of earthwork can be roughly determined by measuring the width of the path and the sidelong slope of the ground. We can then calculate the area of the path with the *mean* sidelong slope, and this multiplied by the length will give the volume of earthwork, provided due allowance for the rock that will probably be found on the line of the path is made.

In order to make a detailed estimate of the cost of making a road or path, a longitudinal section along the centre line of the road, and cross sections at regular intervals and where the slope of the ground changes materially, are required.

Then the longitudinal section of the formation surface (formation level) is drawn on the section, giving the central height above or depth below the ground surface (see Fig. 32, page 100); this measurement is transferred to the cross sections. It can be scaled off the section, but is more accurate if calculated from the level readings and the gradient slopes.

The *formation level* is the finished surface of the earthwork to receive the metalling.

Figure 33 shows how the longitudinal section along the centre line of a road should be made, how the formation level is put on to it, and how the information regarding the depths of the cuttings and heights of the embankments are entered. The vertical scale is not the same as the horizontal scale. Usually the vertical scale is 10 times as large as the horizontal scale. For example, if the horizontal scale is 100 feet to the inch the vertical scale would be 10 feet to the inch. The vertical scale should not be less than this, since the smallest measurement which can be shown on this scale is one-tenth of a foot. In England the cuttings are generally coloured red, the embankments green, both in the longitudinal and cross sections. The character of the soil traversed should also be shown on the longitudinal section just below the ground line, to allow of the proper changes in the side slopes of cuttings and embankments, etc., being made.

FIG. 33.

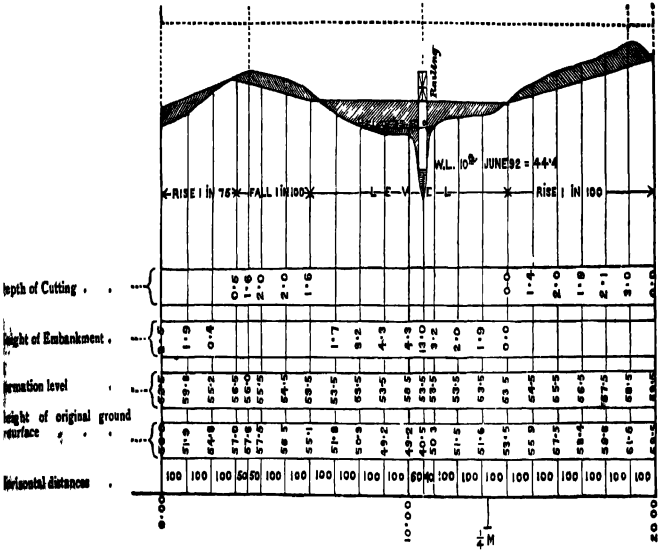

Figure 33 is a longitudinal section of a road showing the original ground surface, the formation level, gradients and depths of cuttings and heights of embankments. All the measurements are expressed in feet.—(U. N. Kanjilal.)

The *formation level* is chosen by trial. Several alternative lines are ploted on to the longitudnal section, and the best of these (*i.e.*, the one which allows of the most suitable gradients with the least amount of cutting and embankment, and equalizes, as far as possible, the amount of cutting and embankments) is finally selected and plotted definitely on to the longitudinal section.

The height of the formation level above or below the reduced level (*i.e*, the level of the surface of the ground) at the first point is measured off with a pair of dividers, and the distance is then read off the vertical scale (2·5 feet in Fig. 33). All the other figures opposite to the headings depth of cutting or height of embankment are calculated mathematically, since the distances between all the intermediate points are known, and also the rise or fall between them. The cross sections (examples of which are shown in Figs. 34 to 38) at the different points are determined as follows. The actual surface of the ground (AB, Figs. 33 to 37) is plotted at each of points in succession. The height of the formation level (CG, Figs. 34 to 38) above or below this point is then laid off. The width of the road DE measured off and the slopes of the cuttings or embankments (AD, EB, Figs. 33 to 37) are drawn at the natural angle of repose for the soil in which the cutting or embankment is to be made.

Figures 34 to 38 show all the possible forms of cross sections that may occur ; the surface of the ground may slope, as regards the surface of the road, either longitudinally (Figs 34 to 38), or transversely, (Figs. 35, 37 and 38) or both longitudinally and transversely (Figs. 35, 37 and 38) at the same time.

In order to determine the actual volume of earthwork in the cuttings and embankments we must take cross sections at every point on the longitudinal section at which the slope of the ground changes materially, and all these cross sections must be plotted in regular succession. The volume of each cutting and embankment must be taken out separately, and is determined (see formulæ on page 105) as soon as the areas of the consecutive cross sections and the distances between them (these are given in the longitudinal section) are known.

The formation width and the slope of the sides must be determined for each cutting and embankment according to the requirements of the road and the nature of the soil. The formation surface may be considered as a plane surface when calculating the volume of earthwork.

The following sketches show the different shapes of cuttings and embankments:—

FIG. 34.

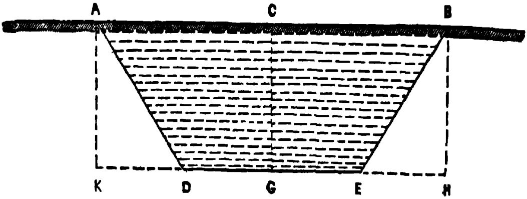

Figure 34 shows a cross section of a cutting where the ground surface is level or inclined in the direction of the length of the road only.

FIG. 35

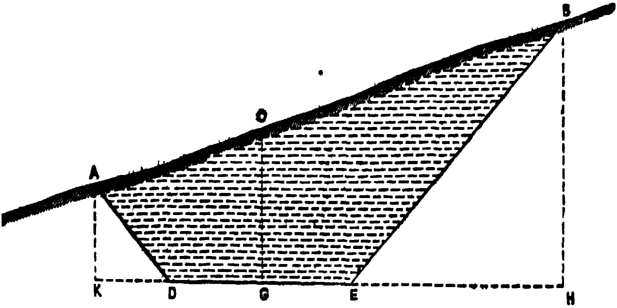

Figure 35 shows a cross section of a cutting where the ground surface has a sidelong slope, and may or may not have a slope in the direction of the road

FIG. 36.

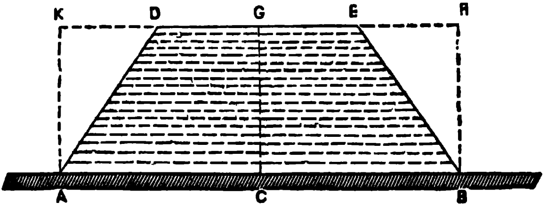

Figure 36 is a cross section of an embankment made on ground which is level, or slopes only in the direction of the road only.

FIG. 37.

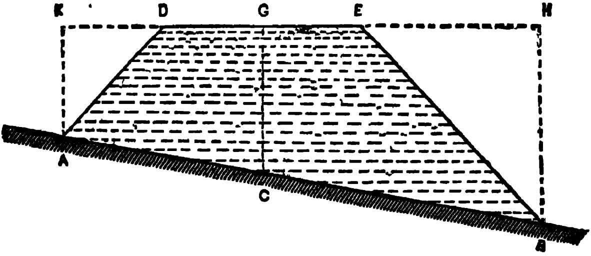

Figure 37 is a cross section of an embankment where the ground surface may or may not slope in the direction of the road, but has a sidelong slope.

FIG. 38.

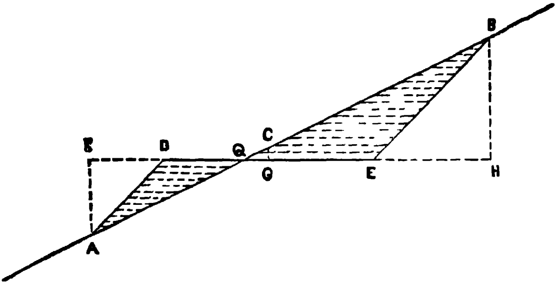

Figure 38 is a cross section of a road formed on sidelong ground partly by cutting and partly by embankment.

In the foregoing figures C represents a point on the centre line as laid out on the original ground surface AB is the original surface of the ground. DE is the formation surface G is the point where it is cut by the vertical plane of the centre line The relative height of the formation surface above or below the original surface of the ground is fixed by the formation level. CG is the height of the embankment, or depth of the cutting at the centre line. A and B are points on the side-widths of the road. BH and AK are perpendicular lines drawn from A and B to meet the horizontal surface of the road produced in K and H respectively. The ratios of EH : HB and AK : KD are the natural slopes of the earth in the cuttings or embankments.

The area of the cutting ADEB in Fig. 34 is $\frac{AB + DE}{2}$ CG.

The area of the cutting ADEB in Fig. 35 is $\left(\frac{BH + AK}{2}\right) HK - \frac{AK \times KD}{2} - \frac{BH \times EH}{2} = \frac{BH \times KE + AK \times DH}{2}$.

The area of the embankment in Fig. 36 is $\frac{AB + DE}{2}$ CG.

The area of the embankment in Fig. 37 is

$$\frac{BH\ KE + AK\ DH}{2}$$

In Fig. 38 the area of the embankment ADQ is $\frac{AK \times D}{2}$.

The area of the cutting QBE is $\frac{BH \times QE}{2}$.

If r . 1 represents the gradient of the road, and s : 1 represents the cotangent of the angle of repose for the soil in cutting or embankment.

If GC= h and DG=GE=b=the half breadth of the road.

Then the area of the cutting in Fig. 34 and of the embankment in Fig. 36 becomes

$$h\,(2\,b+s\,h).$$

The area of the cutting in Fig. 35 and of the embankment in Fig. 37 is

$$\frac{r^2 \times s}{r^2 - s2}\left(h + \frac{b}{s}\right)^2 - \frac{b^2}{s}$$

$$\frac{sb^2 + 2r^2hb + r^2sh^2}{r^2 - s^2}$$

And the area of the cutting in Fig. 38 is

$$\frac{(b+rh)^2}{2(r-s)}$$

And the area of the embankment in the same figure is

$$\frac{(b-rh)^2}{2(r-s)}$$

The volume of the earth between the cross sections is given by the formula

$$V = \frac{S_0 + S_1}{2} \times x.$$

Where V is the volume of the earth, S_0 and S_1 are the respective areas of the cross sections and x the horizontal distance between them. The cutting or bank is divided into convenient lengths, each satisfying the condition that the [surface line and the formation level line are straight for that length. This formula, taking the arithmetical mean area of the trapezoidal cross sections, gives results somewhat in excess of the true volume, except when the cross sections are equal.

The original surface of the ground must slope uniformly between the two cross sections taken.

The total volume of earthwork for any cutting or embankment is given by the following formula:—

$$C = V_0 + V_1 + V_2 + \text{etc.}$$

where C is the total volume of the earth in the cutting of embankment as the case may be, and V_0, V_1, V_2, etc., are the volumes of earth between the consecutive cross sections which have been taken.

The volume of earth in any cutting or embankment may be taken out *graphically* by plotting all the areas of the cutting or embankment taken at the different cross sections to scale, and taking out the area of these either by the planimeter, or else by reducing the figures graphically to triangles and then taking out their areas.

§ 86. ESTIMATE.—When the construction of a cart-road will involve the expenditure of a considerable sum of money, carefully prepared plans and estimates should be prepared in order to find out the cost of its construction. The volume of earth and stone to be removed is estimated. The cost of the construction of such bridges and culverts as are necessary, as well as the cost of metalling, should be shown separately. The provision for the drainage of the road is to be clearly specified. A report showing the necessity for and the nature of the proposed road, its general direction and the reasons which have influenced the choice of route, the nature of the country traversed, the obligatory points and the reasons which have determined their selection, the proximity of suitable materials for metalling the road, as well as for the construction of necessary buildings, bridges, culverts; the nature and quantity of the traffic which exists at present and its expected development, should accompany the estimate proper.

The chief items of expenditure may be arranged under the following heads:—

(1) Surveying expenses.
(2) Alignment of road.
(3) Earthwork at the rate of 1,000 cubic feet.
(4) Metalling at the rate per 100 cubic feet or superficial feet of a given thickness.
(5) Construction of drains and culverts at so much per 100 cubic feet of masonry or brickwork.
(6) Blasting at so much per 100 or 1,000 cubic feet, or at the rate per foot of hole bored.

(7) The cost of bridges; the total cost of the bridges should be entered in the general estimate, but the cost of each bridge must be calculated separately and submitted with all necessary drawings showing its construction.

(8) Fencing and parapet and retaining walls.

(9) Superintendence at so much per cent. on the total expenditure.

The specification accompanying the estimate should show—

(*a*) Where the earthwork for the construction of the embankments is to be obtained, whether it is to be dug from side cuttings or not, as well as the way in which the earth is to be removed from the cuttings and consolidated to form embankments.

(*b*) Where the metalling is to be obtained from and how it is to be laid down.

(*c*) The nature of the masonry or brickwork of the culvert and small bridges, as well as that of the retaining and parapet walls. If railings are to be added, the materials to be used and method of construction should be given. Separate specifications should be submitted for the more important bridges and culverts.

The following drawings should accompany the report—

(1) A general plan of the road on a scale of 4 inches to the mile, and another on a scale of from 200 to 600 feet to inch.

(2) A longitudinal section on a scale of 200 to 600 feet to the inch, the vertical scale of the section being from 10 to 40 feet to the inch.

(3) Cross sections on a scale of 10 or 20 feet to the inch—

(*a*) Of the ground where it is very irregular or where deviations are likely.

(*b*) Of the finished roadway in cutting, embankment, and on ground with a sidelong slope.

(*c*) Of all streams to be bridged.

(4) Detailed drawing of all important bridges and culverts.

Part IV.—BRIDGES.

SECTION I.—MATERIALS IN COMMON USE FOR THE CONSTRUCTION OF BRIDGES.

§ **87.** Modern bridges of large span, which are required to carry heavy traffic, are usually constructed of mild steel ; which is first wrought into plates, bars and beams of various sections, these being afterwards joined up together in a variety of ways by means of rivets, bolts and pins. The same material is often used in the construction of bridges of small span required to carry heavy traffic, and also occasionally in bridges made to carry light traffic.

A forest officer in India will rarely be required to construct bridges of large span to carry heavy traffic ; and consequently the information given in this part will only refer to the construction of bridges of comparatively small span, (except in the case of hill suspension bridges required to carry light traffic) and bridges strong enough to carry a string of loaded carts or an elephant.

In the plains of India, forest cart-roads used throughout the year are uncommon. The export of forest produce in carts usually takes place in the dry season of the year, when the beds of torrential streams are nearly, if not quite, dry ; and when carts can be taken across the beds of the streams themselves, provided properly graded inclines are made connecting them with the existing fair weather roads. This being the case, an Indian forest officer will not often be required to construct a bridge even sufficiently strong to carry a loaded cart. Where, however, a cart-road is used throughout the year, bridges should be constructed across all river-beds which are liable to be in flood during the rainy season. Although the total length of such a bridge may be considerable, it can nearly always be constructed of a number of arches, the individual spans of which need, as a rule, never exceed 40 feet.

§ **88.** By far the greater number of bridges which a forest officer will have to construct, will be in connection with hill export roads, sledge roads, tramways, rolling roads or timber slides. Such bridges will not be required to carry heavy traffic, nor will they, as a rule, have large spans.

For bridging the gaps in forest roads and paths, timber is very largely used on account of its accessibility and abundance. Some iron or steel in the form of nails, bolts and straps, is in all cases necessary, to fasten the parts of the bridge together. When the spans are somewhat large and the traffic great, a combination of timber and mild steel, in which the steel is used for the tension members, and timber for those which are subjected to a bending and compressive stress, will often form the most satisfactory and economical bridge.

§ **89.** In bridging a wide space, where intermediate piers are not admissible, and where the traffic is light, a roadway made chiefly of timber, may be suspended from ropes composed of steel wire, and thus a light and strong, but not very rigid, bridge (known as a suspension bridge) can be formed at a comparatively small cost.

§ **90.** Where no steel wire ropes are available and no intermediate piers are admissible, bridges may be constructed on the cantilever principle. Counterweighted arms are built out from either bank of the space to be crossed, until the distance between the free ends of these arms is sufficiently reduced, to allow of a single beam being thrown across to connect the one with the other.

§ **91.** In carrying a roadway across a wide space, intermediate supports (piers) will be required. These piers divide the space into shorter lengths, which can be bridged with less cost and difficulty. The ends of the bridge rest on abutments which may be constructed of wood, dry rubble stonework, or, where great strength is required, of stones set in mortar.

When a river is being crossed, the piers obstruct the waterway, and may in some cases become seriously objectionable, by arresting the progress of floating bodies, which may block up the space between the piers; and by lessening, to some extent, the section of the channel available for the flow of water. The shock due to the sudden arrest of a heavy floating body such as a tree, or the combined weight of a number of arrested trees, may carry away the whole bridge.

In many cases, piers are indispensable, and the above mentioned considerations should be kept in view in their design, and in the choice of the materials of which they are composed. Masonry piers should only be placed on very reliable foundations, and unless the river is dry at the building time of the year, considerable trouble and cost may be incurred in constructing the foundations.

Timber may be used in the construction of piers, either driven as piles firmly into the bed of the stream, or used merely as props that can be easily removed in time of flood.

Iron and steel beams may also be used, driven firmly into the bed of the stream. Iron tubes which are filled with concrete, after they are fixed in position, will often provide a very efficient pier.

§ 92. In Assam, rails which have been discarded, because they are too much worn for the permanent-way of a railroad are often used as bridge piles. The lower part of the pile consists of a cast iron screw furnished with a socket into which one end of the rail fits. The pile is screwed into the river-bed by means of a capstan-head. In swampy ground, rail piers can be constructed as strong as masonry ones, at a smaller cost by adding a system of cross braces.—(*D. P. Copeland.*)

§ 93. In Bengal, temporary foot bridges are often constructed entirely of bamboos. The piers consist of 4 bamboos firmly fixed into the river-bed. The outer pair are bent inwards towards each other and tied together near their tops, while the second pair are placed inside the first, crossed and tied to the outer pair about two-thirds of the way up. Three bamboos are placed in the notch formed by the second pair of bamboos, and form the footway of the bridge. In some cases a hand rail is put on one or both sides.—(*F. B. Manson.*)

§ 94. When good foundations can be obtained on the banks of the space to be bridged, and stone is easily procurable, arched bridges made of stone laid in lime mortar may sometimes be advantageously constructed. Provided the foundations are well laid and the superstructure carefully erected, such bridges will be very durable and should require little or no expenditure in their maintenance. Bricks may entirely take the place of stone, or may be used for the superstructure only.

Where timber will soon be destroyed by fungi or white ants ; stone, iron or steel should be substituted for it if practicable.

§ 95. In determining the type of bridge to be adopted in any particular case, the choice of the officer responsible, will largely depend upon the designs he may have in his possession of bridges, which under corresponding circumstances, have been found satisfactory, and it is hoped that the following pages may prove of service to him in this connection.

The other important determining factors are, the kind of material suitable for construction which is most easily procurable, and the kind of labour, both skilled and unskilled, locally obtainable.

The question of durability and cost of maintenance is important, in a varying degree, according to the want of a temporary, or permanent, much used or little used construction ; and also on the probable effect of floods. Sometimes the necessity for rapid construction will settle the design, but generally what should be aimed at is the most efficient combination of reliability and smallness of cost.

§ 96. In forest export works, strong bridges of small spans are often required temporarily, while logs or timber are being removed from remote parts of a forest. In such cases the cheapest and roughest construction, consistent with the required strength, should be erected. Such bridges will be usually made of wood, the main longitudinal beams may be formed of trees felled across the obstacle, the upper surfaces being roughly squared in order to support the roadway. Where the sides of the obstacles to be crossed are unstable, the logs which constitute the longitudinal beams of the bridge should rest on wall-plates supported on rough dry rubble abutments, or on wooden posts driven firmly into the ground.

SECTION II.—PRINCIPLES OF CONSTRUCTION.

§ 97. The method of construction and form of bridges varies with (1) the span of the bridge (*i.e*, the horizontal distance between any two of the adjacent supports upon which the longitudinal beams rest); (2) the nature of the obstacle to be crossed, and (3) the character of the traffic, as this affects the amount of the weight which the bridge will have to carry.

If the obstacle to be crossed is wide, but is of such a nature that piers may be constructed at suitable intervals; then the bridge may consist of a series of small spans, and its construction will be comparatively simple. If however no intermediate supports can be placed in the obstacle, then the bridge must be constructed in an entirely different, and more complicated manner.

The character of the traffic affects the load which the bridge has to carry, and thus influences the method of construction, since the heavier the load to be carried the stronger must be the bridge.

§ 98. Bridges may be classified, according to the method of construction, in the following manner:—

(1) girder bridges, *i.e.* bridges consisting of one or more spans, each span being crossed by beams of either

wood, or iron or occasionally stone. The girders themselves may be simple, arched, trussed or otherwise strengthened.

(2) Suspension bridges.
(3) Cantilever bridges.
(4) Arched bridges constructed of masonry or brick-work.

§ **99.** BRIDGES SUPPORTED BY BEAMS.—The limit of the span which can be adopted for beams, or girders of wood or iron, unsupported between the piers or abutments, depends upon the size and strength of the available timber or iron and the nature of the traffic. (See figs. 63, page 149; 69, page 154, 77, page 161.)

In the case of a cart-road, if the span is less than 20 feet, the roadway of the bridge may be carried by plain unstrengthened beams thrown across the obstacle Where the obstacle is more than 20 feet wide, and intermediate piers can be safely constructed, unstrengthened beams may be laid on piers placed at intervals of 20 feet or less, until the obstacle is completely bridged.

In the case of a sledge road or a bridle-path, distances of 30 feet can be spanned with safety by unstrengthened beams of Chir pine (*Pinus longifolia*) 18 inches by 18 inches in section.

When the span is more than 20 and less than 50 feet the longitudinal beams may be strengthened by additional inclined supports fixed either above or below them.

§ **100.** SUSPENSION BRIDGES.—Suspension bridges may be thrown across obstacles more than 50 feet wide and not admitting of any intermediate supports.

In forest works suspension bridges are rarely required to carry wheeled traffic, and have only to be made sufficiently strong to carry laden men or animals.

The roadway of the bridge is suspended from two longitudinal ropes, which pass over the tops of uprights placed on either side of the obstacle (see fig. 8(

90 and 91, page 186). The free ends of the ropes are securely fixed to firm anchorages on either side of the obstacle. These ropes assume the form of a parabolic curve. The roadway is supported on longitudinal beams resting on cross pieces; which are themselves fastened to the longitudinal ropes by smaller ropes called suspenders or suspensors. The suspenders are fastened to the main longitudinal ropes at equal *horizontal* distances.

It is most important, that the main longitudinal ropes should be securely fastened, at either anchorage of the bridge, so as to prevent their being drawn out by the weight of the bridge, and the traffic which passes over it ; in such a manner that the contraction and expansion of the material of which the ropes are made, owing to changes in temperature, is not interfered with in any way.

The longitudinal ropes and the suspenders should be efficiently protected from corrosion or decay, more particularly those portions of them which are buried in the ground, or are not visible and cannot easily and frequently be inspected.

§ 101. CANTILEVER BRIDGES.—A cantilever bridge, like a suspension bridge, is independent of the nature of the obstacle to be crossed. (See fig. 104, page 218.) It consists essentially of two systems of counterpoised beams built out from either side of the obstacle to be spanned. Each system is composed of beams, placed one on the top of the other, so that the end of each beam projects beyond the end of the beam on which it rests, until the width to be spanned is not greater than can be crossed by a single beam. The ends of the beams which rest on the abutment are weighted in such a manner as to render the construction stable.

In order that the cantilever bridge should be stable, it is essential, that the centres of gravity of the systems of counterpoised beams built out from either abutment, should fall well within the base of the abutment, upon which the system of beams rests. The bridge will be most stable, when the centres of gravity of the systems of the counterpoised beams, are vertically above the geometrical centres of the bases of the abutments, on which they rest.

§ **102.** The methods of constructing masonry bridges are discussed in section VII, page 230 *et seq.* Reference should also be made to Vol. I, Part II, section III, page 181, Arches.

Old railway bar bridges are constructed upon the same principles as wooden bridges of the plain strutted beam, trussed beam, or cantilever types.

SECTION III.—SELECTION OF THE SITE AND APPROACHES OF A BRIDGE.

§ **103.** The expense of erecting a bridge may be incurred to lessen the cost of export of timber, or to provide a direct crossing passable at all times of the year, so as to render a forest more accessible. The sites of small bridges on roads are fixed when the road is aligned, as it is impracticable to alter materially, the direction of a road in every case, in order to obtain a somewhat better site for a small bridge. The actual position of a bridge should be fixed, so as to obtain good foundations for its abutments and piers. The best foundation in the case of masonry piers and abutments is, good, hard, durable rock Firm earth will afford a safe foundation for the abutments and piers of small masonry bridges. The ends of the longitudinal beams of wooden bridges may be supported on wall plates, mortised on to tenoned wooden posts, sunk three or four feet into the ground, or on wall plates laid on the surface of firm ground two or three feet from the edge of the gap.

Where the depression to be crossed is shallow, a small area of waterway required, and the current slow, it is generally possible to throw out embankments from either side of the depression, ending in dry rubble, or if necessary masonry abutments, thus materially decreasing the span of the bridge.

When the bridge has more than one span, the piers must be provided with good foundation beds; and if made of masonry, they must rest on solid rock or firm unyielding earth, at a depth below the reach of the scouring action of the stream; a weak substratum may be strengthened by depositing on it a solid mass of concrete of sufficient area and thickness. Piers and abutments must never be merely placed on the surface of the ground. The foundations of masonry piers should be, where practicable, sunk 6 to 12 inches into the rock, and may be stepped into it if its surface is not horizontal.

Good sound earth, or a bed of boulders, affords the best foundation for piers, consisting of a line of wooden posts shown in figure 39, page 122.

§ 104. The sites of the more important bridges crossing large streams should be selected before the construction of the road is commenced; they should be independent of the detailed alignment of the road, and often form obligatory points on its alignment.

The site of an important bridge should be chosen where—

(1) it is in the general direction of the proposed road;

(2) good foundations for the abutments and piers of the bridge can be obtained;

(3) the banks of the river are above flood level, stable and fairly high, and as nearly as possible equal in height;

(4) the narrowest practicable crossing can be obtained, provided the banks are stable.

The general direction of the road should only be deviated from, when it is impossible to find a suitable site for the bridge in a fairly direct line.

Erosion is always greatest at the curves or bends of a river, and such points should, whenever practicable, be avoided when selecting the site of a bridge. High and nearly vertical banks generally indicate firm compact earth and permanence of river channel.

If the banks of the river are subject to rapid erosion by the stream; the eddies caused by a projecting abutment, or other obstruction, may scour away the bed of the stream; or may cut a channel behind the abutment, and thus divert the river from the bridge. Such banks should be protected from erosion by *training* the river above the site of the bridge; *i.e.*, directing its course in such a manner as to confine the stream to its present channel, and to prevent it from undermining or isolating an abutment. The banks of the stream immediately above the bridge itself should be strengthened at the same time. The training works to be effective, must be commenced a considerable distance above the site of the bridge. Some methods of training streams and protecting river banks will be considered in Volume III, Part VII.

Long deep cuttings as approaches to bridges should be avoided if practicable, since special arrangements will be necessary to carry off the drainage of the road in the cutting, so as to prevent its damaging the abutments of the bridge.

§ 105. WATERWAY.—After the site of the bridge has been chosen, the amount of space to be left for the passage of the stream in flood, under the bridge must be determined, that is to say, the amount of *waterway* necessary. Sufficient space should be provided in every case, for the passage of the stream during the highest flood which has ever occurred, with a liberal margin for more water. Space should be left for floating objects, such as logs, uprooted trees and drift-wood which may come down, as well as for the water itself.

In important bridges it is necessary to make elaborate calculations as to the volume of water passing under the bridge, but for ordinary forest bridges this is not often necessary. In streams subject to heavy floods, the abutments of the bridge should not be built out into the river-bed, so as to diminish the area of waterway, and thus increase the rise of flood water above the site of the bridge, thus causing a more rapid current and greater risk of scouring action on the bed of the stream at the site of the bridge. A great deal of useful information regarding the waterway necessary for a river in flood, can be obtained by examining such traces of high floods as may exist; and by making local enquiries in the neighbourhood, as to the height to which the stream rose, during the greatest flood which can be remembered.

The best time to make such observations and enquiries is at the close of the rainy season, while traces of the floods which have recently occurred will still be easily recognized. The height of the roadway of existing bridges above the river-bed should be noted as well as those of any temporary bridges which may have been destroyed in previous floods.

Sufficient information may thus be obtained to determine the height above the stream of the roadway of bridges constructed departmentally for forest works.

In localities where streams are liable to heavy floods, a very liberal amount of waterway must always be allowed; as unless this is done, a bridge may be carried away as soon as built by an unusually high flood, such as may only occur once in ten years.

Where heavy floods occur, it is better to make a bridge of a few large spans, than one of a great number of small ones ; and where headway is limited, any trussing should be above and not beneath the longitudinal beams, especially where drift-wood comes down the river. Overhead trusses require to be tied together laterally to prevent their spreading.

§ 106. APPROACHES TO THE BRIDGE.—The approaches to a bridge should always be above the flood level of the stream; as, if this rule is not attended to, the stream in flood may flow over and cut away the embankments and leave the bridge standing in the middle of the bed of the stream.—(*F. A. Lodge.*)

Long and deep cuttings leading to a bridge should be avoided for the reasons given on page 118, § 104.

When the level of the finished bridge is either considerably above, or considerably below, the level of the road, on one or both sides of it, care must be taken to give proper gradients (these depend upon the class of road on which the bridge is) to the approaches to the bridge.

The level of the finished bridge may be considerably above the level of the road or path on one side of it, in the case of a stream which has a very wide bed, and only actually occupies a small portion of it; where there is a steep and high bank on one side only, and when the main bed of the stream sets right against this high bank, and cuts its bed lower here, and thus leaving the remaining portion of the bed dry, and only slightly higher than the channel it itself occupies.

The bridge over the river Asan at Dermawala on the Saharanpur-Chakrata Road, just north of the Siwalik Range, is an example of this.

The level of the finished bridge is frequently considerably below the levels of the paths leading down to it on either side, in the case of paths in the hills, crossing large streams flowing in confined valleys; and in such cases care must be taken to give suitable gradients to the approaches of the bridges that are built.

The gradient of the road or path approaching a bridge should be as gentle as possible, and should never exceed the maximum gradient allowed on the class of road which is being constructed (see page 34, § 37) even for a short distance. If the direction of the road is not in the same straight line as that of the bridge, the approaches to it should be given as gentle a curve as the nature of the ground will allow without incurring a considerable additional outlay. A curve of from 50 to 100 feet radius is suitable for a cart-road.

§ 107. THE WIDTH OF A BRIDGE.—The width of a bridge depends upon the character of the traffic which passes over it, and to a certain extent upon the intensity of that traffic.

For a cart-road a width of from 8 to 12 feet for a single, and 12 to 18 feet for a double track will be sufficient; while for a footpath or a path for mules and other pack animals a width of from 5 to 8 feet should be allowed.

Where the amount of traffic is small, the width of the bridge need only be sufficiently wide to allow of one vehicle or pack animal crossing it at one and the same time.

SECTION IV.—SIMPLE WOODEN BRIDGES.

§ 108. In all constructions of wood, it is an axiom that all woodwork should, as far as possible, be exposed to view. A simple wooden bridge consists of the following parts :—

(1) The abutments and piers which support the longitudinal beams.

(2) The longitudinal beams upon which the roadway and railings rest.

(3) The trusses which strengthen and stiffen the longitudinal beams.

(4) The roadway and railings.

§ 109. PIERS AND ABUTMENTS OF WOODEN BRIDGES.— The piers of wooden bridges are ordinarily constructed of wood, stone, or both combined, and occasionally of iron. The shape of the pier depends upon its situation and surrounding; for instance, in the case of bridge over a river-bed, which is dry for the greater part of the year, but which may contain a considerable volume of water during the rains, the piers should be constructed so as to offer the least possible resistance to the passage of the water, and should consequently consist of a single row of posts, in line with the direction of the current, strengthened by struts and braces as shown in figure 39, page 122. The individual posts which make up the pier (*c*, *c*, fig. 39) should, where practicable, be driven or screwed into the river-bed (and are then known as *piles*,) as far as possible below the scouring point of the bed of the stream.[1]

The posts used for the uprights of the pier (*c*, *c*, fig. 39) should, in the case of cart-roads, be from 10 to 14 inches in diameter, and may be roughly squared. If the roadway of the bridge is less than 15 feet above the bed of the stream, the piles which are driven into the river-bed will form the piers of the bridge. But if the roadway of the bridge is so far above the bed of the stream that sufficiently long piles cannot be obtained of the required dimensions, a capsill timber is mortised, and strapped or bolted, on to the levelled and tenoned heads of the row of piles; or a beam is bolted on to each side of the row of piles, level with the top; and the beams forming the pier are supported by pieces of wood bolted or spiked to either side of the piles.

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[1] As has been already noted, the streams which have usually to be bridged by Forest Officers only contain water during a few weeks or months (as the case may be) in the year and are perfectly dry for the rest of the year. When these streams come down in flood during the rainy season, the bed of the stream becomes saturated with water and often becomes perfectly unstable and in some cases (where the river-bed is made of sand) quite liquid. The foundations of the piers must be taken down below this depth, and founded in the stratum below, which is unaffected by the floods which pass down the bed of the stream.

FIG. 39.

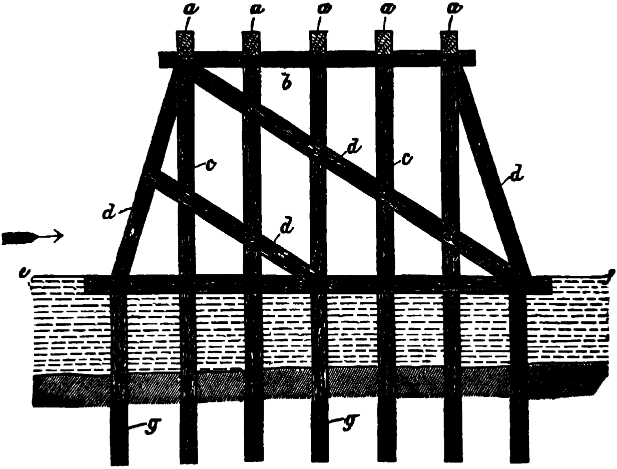


Figure 39 is an elevation of a pier consisting of a single row of piles and posts for a cart-road (after Tredgold). *a, a are the longitudinal beams of the bridge. These rest on a cross piece b, which forms the head of the pier; c, c are the upright posts of which the pier is made; d, d are struts added to stiffen the construction; e, f is the level of the water; g, g are the piles which are driven into the river-bed. The arrow shows the direction of the stream.*

The pier may be strengthened by the addition of diagonal braces bolted to the uprights in pairs, one on either side. These braces (*d*, *d*) should be arranged, as shown in figure 39, so as to enable the pier to effectually resist the force of the stream when in flood. Inclined beams (struts *d* (figure 39), should also be added, at any rate on the up-stream side of the pier, so as to throw the force of the stream in flood off from the pier itself;

if similar struts are added on the down-stream side also, they will materially strengthen the structure.

The piles driven directly into the river-bed are sometimes tied together, by horizontal bracing timbers bolted on opposite sides of the posts, at about low water level.

If the pier is a tall one, horizontal bracing timbers may be fixed at vertical intervals of 10 or 15 feet.

For a stronger and more lofty pier, two or three rows of piles may be driven into the river-bed; and their heads connected together by longitudinal and transverse capsills, mortised and notched: the upright posts of the pier stand on this pile frame-work. Where the road crosses, the stream diagonally, the piles of the piers should be placed in line with the direction of the current of the stream, thus causing the least resistance to the passage of the water when in flood.

The consideration of the different kinds of piles, and the ways in which they may be driven, is discussed in detail in the following paragraphs.

§ 110. PILES.—Timber piles are trunks of trees either round, roughly squared, or rectangular, in section, and pointed at one end. They generally vary in size from 6 to 16 inches side or diameter; and in length from 20 to 45 feet.

The heart of the tree should be in the centre of the pile; the wood straight in grain, free from transverse knots, specially dead ones, sound and well seasoned. The piles must be straight; and in some cases two opposite sides, or all the sides, are hewn or sawn straight and parallel. Squared or rectangular piles may be driven down with the more solid end uppermost, or *vice versâ* for hard woods.

Long piles may be built up of short logs by fished butt joints (see Vol. I, page 107, fig. 28), the butt ends to be cut level and true, and one or two wrought iron fishplates (say flat bars 2½ inches by ⅝ of an inch) bolted or spiked to each face of the piles at the joint; the length of the fishplates being 24 to 30 inches for a full sized pile.

Large piles are built up of two or four ordinary piles grouped together, dowelled and bolted with wrought iron bolts or, for more temporary work, held together by dog irons.

Piles are generally used as *bearing piles* sustaining a vertical loading ; for special purposes they are sometimes used in an inclined position and are then called *raking piles* They are driven into the ground until it is considered that they will bear without yielding the intended load ; the resistance to penetration offered by the soil and its friction against the sides of the pile being together greater than the maximum effort for penetration under the load.

The unsupported length of pile should not exceed 20 times its side or diameter. Straight cylindrical sticks with the bark left on are sometimes used, they are driven with the butt of the tree uppermost, receiving the blows of the ram.

Timber piles driven into loose or soft ground, such as mud, peat, etc., offer but little resistance to lateral pressure. To enable such piles to resist lateral pressure, they must either be driven deeply into a firm substratum, or the soft ground must be displaced by depositing sound earth, sand, gravel, broken soft rock, etc., to form a bank of compact ground, into which the piles are to be driven.

When a group of bearing piles has to be driven, the heads are generally cut off to a horizontal plane, and longitudinal or transverse capsill beams are mortised on to tenons cut on the tops of the piles. In some cases the capsills have notched on to them longitudinal or transverse beams, as the case may be, thus forming a rigid skeleton frame-work. If a masonry pier is placed on a pile foundation, a mass of hydraulic lime or cement concrete, 2 to 3 feet in thickness and upwards, thoroughly compacted by ramming, should be formed surrounding and embedding the pile heads.

Piles are also used to form a close jointed wooden wall (*sheeting piles*), and for this purpose rectangular piles may be used ; they are driven down with the sawn narrow edges in close contact ; they vary in size from 2 inches thick by 9 inches wide, up to about 12 inches square.

A close jointed, almost watertight, wall may be made of soft wood sheeting piles, by cutting a groove in both contact sides, and driving into it a tongue of hard wood or a flat bar of wrought iron 3 to 4 inches wide and ⅝ inch thick.

In selecting piles for a particular work, a boring tool may be used to explore the nature of the substrata, into which the piles are to be driven, and from this exploration, the required length of each pile may be estimated; thus saving the cutting of a long pile to waste. About 24 inches extra length must be provided to allow for cutting off the bruised head of the pile.

§ 111. The lower end of a pile is pointed to facilitate penetration, and for all, except very soft soils, this point must be shod with wrought iron, cast iron, or compound shoes. The length of taper of the point is from one and a half to twice the side or diameter of the pile.

A simple pile shoe for light work is made of wrought iron or steel plate, three-eighths of an inch thick, bent into the shape of a hollow cone, with a vertical folded joint, interlocked and rivetted through, the extreme point or apex may have a solid conical point about 2 to 4 inches long welded in. For an 8 inch pile such a shoe may be 14 inches high and 7 inches diameter at its widest part. A shoe of similar shape may be made entirely of cast iron from ⅜ to ⅝ inch in thickness.

Another form of shoe is built up of a solid wedge-shaped or pyramidal point of wrought iron, into which flat bars about 2 inches by ⅜ inch by 18 inches long are welded: these bars or straps are spiked to the tapering sides of the wooden pile point.

Light cast iron shoes are liable to crack when driven into contact with hard stony ground, and light wrought iron strap shoes may be wedged open, or the point may be turned aside and the straps crumpled up.

A good pattern of shoe (figures 40, 41 and 42, page 126) is a compound shoe made up of a cast iron point fitted with wrought iron bar straps. The cast iron point, wedge shaped or pyramidal, should furnish a base about 4 to 6 inches square, to give a good bearing surface for the end of the pile. The straps may be united to the cast-iron point by soft iron rivets, cast in the wedge-shaped cast-iron points; grooves may be cast in the two wide faces, as shown in figures 40, 41 and 42, to receive the ends of the wrought iron straps.

FIGS. 40 & 41.

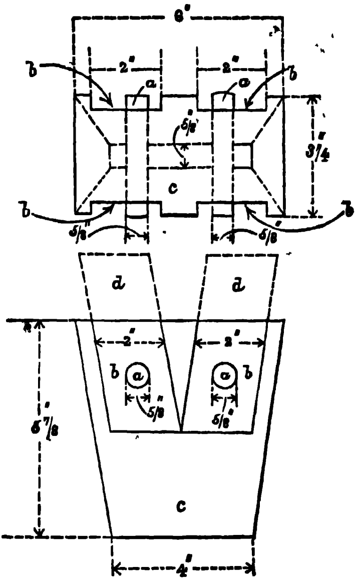


FIG. 42.

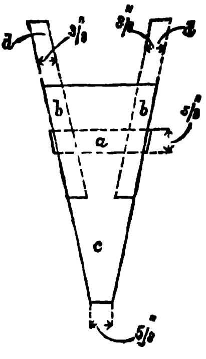


Figure 40 is a plan of a compound shoe, consisting of a solid cast iron point c, with wrought iron bar straps. The bar straps are omitted in the figure. The parts of the cast-iron point and soft iron rivets a, a, which are not seen, are indicated by dotted lines. b, b are the grooves cast in the two wide faces to receive the bar straps.

Figure 41 is a front elevation of the shoe c is the solid cast-iron point. The dotted portions d, d above indicate the position of part of the bar strap. a, a are the soft iron rivets, b, b the grooves cast in the cast iron point.

Figure 42 is a side elevation of the shoe, letters as in figures 40 and 41. Scale = ¼.)

The pyramidal point may be cast as two co-axial pyramids superposed, the upper one being truncated and having 8 sides at the larger and 4 sides at the smaller end (see figures 43 and 44), thus giving a shoulder covering the ends of the wrought iron straps.

FIG. 43.

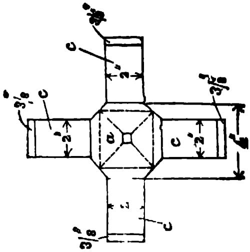


FIG 44.

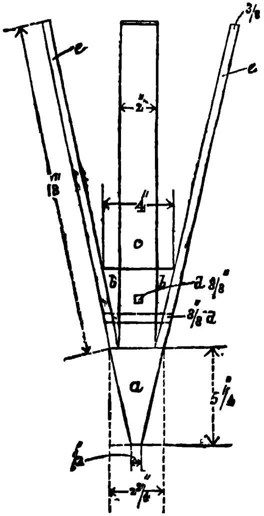


Figure 43 shows in plan a pyramidal pointed shoe, cast as two co-axial pyramids and fitted with wrought iron bar straps.

Figure 44 is an elevation of the same shoe.

a is the pyramidal point, b is the upper co-axial truncated pyramid partly hidden by one of the straps c, c, c, c. d, d (figure 44) are the bolts fastening the wrought iron straps to the solid cast iron point. They are omitted from figure 43. The dotted lines in figure 43 show the shape of the lower of the two co-axial pyramids. (Scale = 1/8.)

A large cast iron shoe (figures 45 and 46) for 12 to 14 inch square piles was of ¾ inch metal, an inverted four-sided pyramid 16½ inches high; socket to receive the wood point of the pile 8 to 9 inches deep, 3 spike holes in each side of the socket, solid apex, and point 1 inch square and rounded.

FIG. 45.

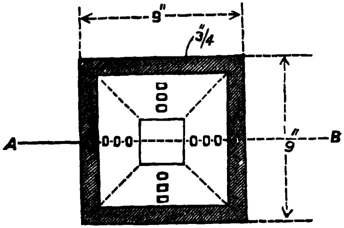


FIG. 46.

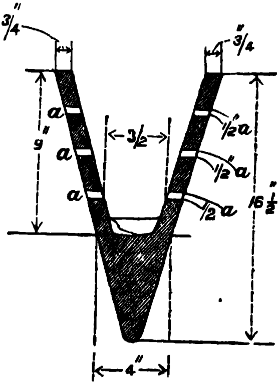


Figure 45 is the plan of a large cast-iron shoe, while figure 46 is a vertical section along the line A B to show its construction. a, a are the spike holes. (Sale=¼.)

Similar shoes, wedge shaped, and with one narrow side vertical and coinciding with the face of the pile, and the other inclined to the vertical, are used for sheeting piles. This form of shoe facilitates the driving of the piles with the narrow edges in close contact.

§ 112. The heads of the piles receive blows from a heavy ram of hard wood or cast iron, and it is generally necessary to hoop them to prevent splitting. The head of the pile is trimmed gradually to a cylindrical shape, and a welded hoop of wrought iron is shrunk on. The hoop may be 2 inches by ⅝ inch flat bar for small piles, up to 4 inches by 1 inch for large piles. The hoop is to be 2 to 4 inches below the top of the pile, so that the falling weight will not strike it. A hoop, square in plan with rounded corners, may be used for square piles and a similar or oblong hoop for rectangular piles.

§ 113. PILE DRIVING.—For a small pile, a tenon is cut on the head, and on the tenon is fitted a slab of hard wood, say 4½ feet by 2½ feet by 3 inches thick, with a central mortice hole. Two men standing on the slab raise and let fall on the pile a hard wood rammer 60 to 70lbs. in weight ; the height of the lift is from 3 to 3½ feet, the weight of the men adds to the effect of the blow. Sometimes two slabs are fitted on at right angles, on which four men can stand and raise a 120 to 145lbs. rammer.

Another simple method is to plant a wrought iron bar, 1¼ to 2 inches in diameter in the axis of the head of the pile, penetrating to a distance of about 12 inches. The bar is 7 to 8 feet long, and serves as a guide to a barrel-shaped rammer of hard wood, say 9 to 12 inches in diameter and 3 feet long, or more. Four equidistant handles of ¾ inch wrought iron bar are screwed vertically to the side of the rammer, which has a cylindrical hole bored along its vertical axis, to admit the guide bar. The rammer must be well hooped with wrought iron bar near each end. A platform for the men lifting the rammer may be attached to the pile head, or may be an independent structure.

§ 114. For forest works in Upper Burma the pile driver shown in figure 47 has been found very useful by Mr. M. Hill, Deputy Conservator of Forests, to whom I am indebted for the description and illustration. The pile driver is extremely simple and easily set up, and is well adapted to the construction of pile bridges across small streams. It consits of a pole *e* (fig. 47) of any suitable wood about 6 inches in diameter and about 16 feet in height; to this is attached by bolts and nuts a traingular frame, *c*, made of pieces of wrought iron welded together, the horizontal arm of this frame is broadened out at the end to form a ring *l*, through which an iron guide rod *b*, three-quarters of an inch in diameter and about 15 feet long, moves freely. The weight or monkey *a*, which works up and down this rod, is made of sâl, (*Shorea robusta*) or any other heavy wood. It is bound 2 inches from either end with iron bands 1½ inches wide and ⅜ inch thick *h*, *h* to prevent it splitting; through the centre, a hole is bored in which the iron rod can move freely: a block of sâl wood, 15 inches long and 10 to 12 inches in diameter, weighing about 73lbs., is used in Upper Burma.

Figure 47 is a sketch to show the construction and method of use of a small pile driver used in Upper Burma. d is the pile to be driven, a is the monkey which is raised by men pulling at the small ropes fastened to the rope g, which is attached to the iron handle l, spiked on to the monkey a. The rope g passes through a pulley k, suspended from a hook m, resting in the eye of a bolt which connects the wrought iron stay f with the horizontal arm of the wrought iron bracket c. The monkey a works on a vertical rod b. The lower end of this rod is embedded a few inches in the centre of the upper end of the pile to be driven, while its upper end passes through the hole l in the free end of the horizontal arm of the iron bracket c. The wrought iron bracket c is bolted to the upper end of an upwright post e securely fastened to trees near by, or to posts driven into the ground for that purpose. The position of the post e is fixed so that the rod b is truly vertical. The bracket c is made of bar iron, but may conveniently be made of angle iron 2½ × 2½ × ⅜ inches, welded to the required shape. Scale 4 feet to the inch —(Drawn by M. Hill.)

Figure 48 shows in plan and figure 49 in elevation the construction of the end of the horizontal arm of the frame c : the letters are the same as in figure 47. (Scale $=\frac{1}{15}$).

FIG. 47.

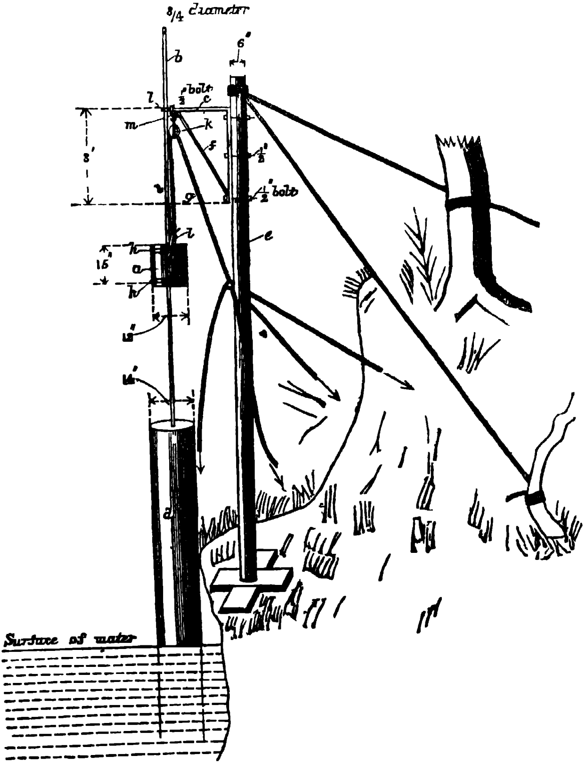


FIG 48

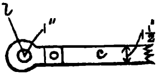
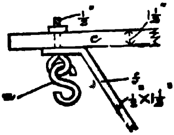


FIG. 49.



A rope *g* passing through a pulley *k*, attached to the horizontal arm of the frame *c*, is fastened to an iron handle *l* spiked on to the monkey. The rope has four or more ends to allow of a number of men pulling together. The pile driver is fixed in position, and held by two or more ropes attached to any convenient objects. A framework *f* may be placed at the base of the pole *e* to increase its stability. At the top of the pile *d* a small hole about 3 inches deep is made to receive the lower end of the guide rod *b* to keep it in position.

The pile while being driven is kept in position by ropes (not shown in the figure), and these ropes are adjusted from time to time in order to keep the pile perpendicular.

The monkey is drawn up by men, till close to the pulley, and then suddenly let go. No catching or releasing gear is necessary, and the coolies will not use it if it is attached. As the pile is driven in, the iron guide rod moves with it, thus adjusting itself automatically with each stroke. The number of men employed depends upon the weight of the monkey used. It is not necessary that the pole *e* should be perfectly upright, it may be inclined at a considerable angle, so long as the rod *b* moves freely through the ring *i*.

§ 115. The "*ringing engine*," figures 50, 51 and 52, is an efficient, handy and simple machine for pile driving. It consits of two upright timbers, 4 to 6 inches square (*f*, *f*, figs. 50, 51), each standing on and tenoned into horizontal sills of similar dimensions (not shown in figure). These uprights have a clear space between them of 4 or 5 inches and in this space the ram, or a projecting portion of it, slides freely. The upright timbers or guides (*f*, figs. 50, 51) are each tenoned into a horizontal timber or capsill *d*, which carries a casting *b*, forming a bearing for the journal of a sheave *a* which is 20 to 24 inches in diameter.

Over the sheave passes a stout rope 4½ to 6 inches in girth (not shown), attached at one end to a heavy ram (fig. 52) of hard wood, hooped near each end, or of cast iron sheathed with ⅜ inch wrought iron plate, with a projecting vertical feather at the back (seen dotted in figure 52); at the other end of the rope are attached 8 to 20 smaller ropes about 1½ inches in girth, called hand ropes, one rope being allowed for each workman.

FIG 50

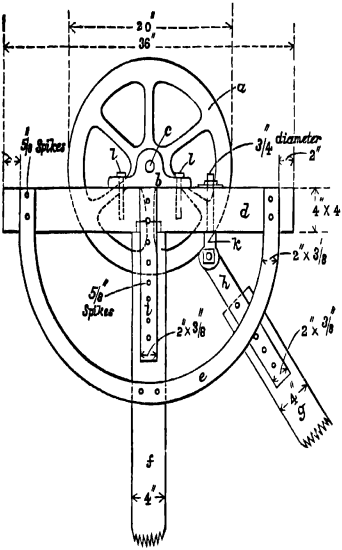
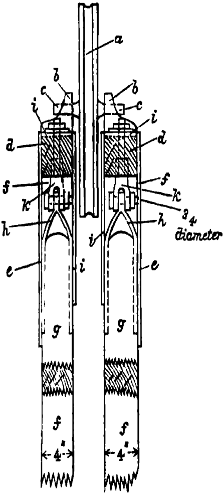


FIG 51.



Figures 50 and 51 show the detail of the top of a ringing engine for driving piles Figure 50 is a side elevation, and figure 51 an end elevation The same letters are used in both figures f, f are the upright timbers, to which the capsills d, d are joined by the straps i, i. The uprights are tenoned into the capsills, and the joint is further strengthened by the strap e The castings b, b which carry the journals c, c of the sheave a are fastened by two wood screws l, l to the top of the sills. g, g are the strutting timbers which form the backstays of the pile driver. The detail of the hinged joints by which they are fastened to the bolts k, k which pass through the sills is shown in figure 51.

The feathered projection of the ram, fig 52, slides between the two uprights f, f, fig 51. (Scale = $\frac{1}{11}$)

FIG. 52

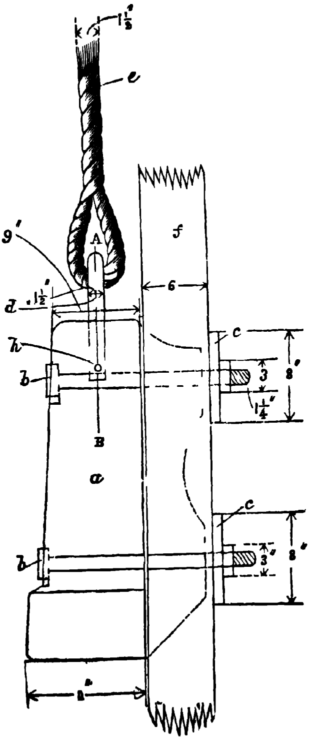


FIG. 53

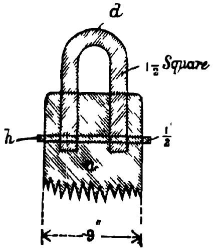


Figure 52 shows in side elevation the ram of the ringing engine a is the ram, the portion shown in dotted line slides between the two uprights f, f of the ringing engine, fig 51. c, c are the large washer plates fitting losely at the back of the uprights f, f which keep the ram in position b, b are the bolts which fasten the washer plates to the ram. A staple (square in section) d is let into the top of the ram and is kept in position by a cotter pin h e is the rope fastened to the ram and passing over the sheave (a, fig 50), by means of which the ram is raised when required Fig 53 is a section along the line A B, fig 52 to show how the staple is fastened to the ram (Scale=1/12)

The ram is lifted by all pulling smartly together at the hand ropes, and then suddenly slackening, and allowing the jerked up ram to fall freely on the pile head. The ram rises about 4½ feet if smartly pulled up. The feather at the back of the ram or monkey slides freely between the guide timbers, and is held there by two large washer plates (*c*, *c*, fig. 52) fitting loosely at the back of the guides and bolted to the ram.

To each upright timber *f* there is a strutting timber (*g*, fig. 51) or backstay, hinged with a knuckle joint to a bolt *k*, passing through the capsill *d*, and extending behind the uprights, the backstays are sometimes shod with a helmet-shaped hollow casting (or 3 or 4 wrought iron flat bar straps placed equidistant and welded together at one end to form a point) to facilitate fixing in the ground. Side struts are also used, extending from the projecting horizontal sill timber, to the side of the uprights at one-third to one-half their height. These are not shown in figure 51.

The weight a man can lift for a day's work averages from 35 to 40 lbs, and about 20 men is the greatest number that can be efficiently employed at the hand ropes; 12 men is usually the maximum. The ram will therefore weigh from 800 to 480 lbs. as a maximum, it should be at least equal to the weight of the pile where practicable. The number of blows given per hour may average 12 volleys of 30 blows each, the men taking a short rest after delivering a volley, sometimes a volley lasts 3 or 4 minutes, and 400 to 500 blows are given per hour with 40 or 50 blows in a volley.

§ 116. *Pitching and driving a pile.*—The timber pile is brought up to the foot of the pile engine and placed accurately in position; sometimes a shallow pit is dug to receive the point. It is then fastened to the pile engine, or to convenient fixed points close by, so that it will be guided in its descent, in the former case it may be lashed or bolted to a block of hard wood sliding freely between the guide timbers; in the latter it is encircled by a loose fitting wrought iron hoop which is attached with ropes or chains to convenient fixed points. When the pile is properly secured for guidance, it may be then driven down. If a pile has to be driven down below the platform of the pile engine, a length of hard, tough wood, hooped at both ends (a *dolly*) is commonly used; the blows of the ram received by the dolly may lose from one-half to two-thirds their efficiency for driving the pile. A bruised or besomed out pile head should be cut off down to sound wood, if the length of the pile permits, and the head re-hooped; a bruised head lessens materially the efficiency of the blow of the ram.

To check the malpractice of cutting off the head of an imperfectly driven pile, the side or two sides of a pile should be marked indelibly with the length of the pile, from the pile point, and the figures incised or burnt in, and the head of the pile should not be trimmed to receive the superstructure until the pile driving has undergone inspection.

All pile driving should be under trustworthy supervision, and if the operations are extensive, accurate notes should be taken of the driving of each pile, the number of blows given, weight of the ram, length of fall, distance driven per blow or group of blows, and the time occupied.

The weight of the ram is generally limited by considerations of carriage from place to place and facility of handling; but should, if practicable, be greater than that of the pile to be driven. A heavy ram with a low fall and rapid succession of blows is more effective, and is less liable to cause injury to the pile, than a light ram and a long fall. The penetration under the blows of light ram, should not be less than one-half to one quarter of an inch per blow, according to the hardness of the soil; if less, there is risk of injuring the wood of the pile at either point or head, and the weight of the ram must be increased.

§ **117.** A fine close compact sand offers great resistance to the driving of piles by impact. Comparatively light blows in rapid succession are more effective than heavy blows at long intervals; the sand round the pile may advantageously be saturated with water. A more efficient method is to use a strong jet of water to wash away the sand in advance of the pile point, the water rising up the sides prevents the sand from gripping the pile. The water jet is usually carried down one or more pipes temporarily fixed to the side or sides of the pile. A 1½ inch diameter pipe is generally large enough; two fixed on opposite sides of the pile give good results. The jet may be derived from a line of pipes carrying water from a mountain stream; 50 feet of head may be sufficient; the stronger the jet the greater its efficiency. When the pile has been sunk to the required depth, a few blows are given with a ram and the sand is allowed to settle round the pile.

§ 118. The load which a pile driven into the ground by impact will carry may be approximately ascertained by the following formula of Weisbach.

$$P = \frac{w^2 \times h}{w + m} \times \frac{1}{x}$$

Where P is the extreme load in tons

w = weight of the ram in tons;
h = fall of the ram in feet;
m = weight of the pile in tons;
x = the average penetration per blow (in a series of blows) in decimals of a foot.

A factor of safety of from 5 to 10 is used to give the safe working load. A high factor of safety should be used for a pile driven into soft or wet ground and subjected to strong vibrations.

§ 119. DISC PILES.—When it is required to sink piles in a fine close sand with the help of a water jet, a socketted disc of cast iron or cast steel, may be fitted round the end of the unpointed pile (see figures 54 and 55, page 138). This disc will greatly increase the area of bearing surface and add to the carrying capacity of the pile.

FIG. 54 & 55.

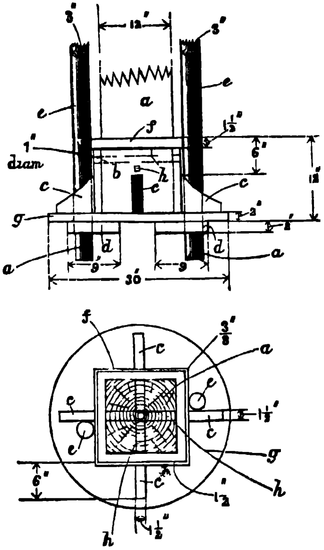


Figure 54 is an elevation, figure 55 a plan of a disc-footed pile a is the timber pile b the socket into which it fits. h, h the bolts which fasten the pile into the socket g the disc proper, circular in plan c, c flanges to strengthen the union of the socket and disc e, e the water jet pipes f the wrought iron hoop which is shrunk on to strengthen the top of the socket. d, d two of the scrapers The scrapers which are arranged symmetrically are not shown in figure 54 (Scale = $\frac{1}{24}$*)*

The casting is bolted to the pile, with two through bolts crossing one another. The disc *g* may be circular, or square in plan, and the socket *b* 8 to 10 inches high, the top being reinforced by a wrought iron hoop *f* shrunk on, the pile may penetrate through the disc, or be seated on its upper surface as shown in the figures. On the under side of the disc may be cast 6 or 8 radiating ribs, *d d*, figure 53, projecting about 2 inches, these ribs may have a serrated edge. The water jet tubes *e*, *e* are brought down the sides of the pile and pass through the disc flange, projecting about 6 inches.

The descent of the pile is facilitated by giving an alternate rotary motion to the disc. A long lever bar, lashed to the pile, is moved forwards and backwards through about ¼ of a revolution of the pile ; the radiating ribs will scrape away any hard material beneath the disc. The piles should be cylindrical if the rotary motion is given, and the water jet tubes should not project beyond the bottom of the disc proper.

Disc-footed piles with underscrapers can be sunk with the water jet to a rock surface and then be made to scrape away the soft rock to a fair bearing.

Disc-footed piles are not driven by impact nor yet screwed down, but sink in virtue of their own weight, the sand immediately below them being washed away by the water jet. They can only be sunk in quicksands, pure sand, soft mud, or any substance that can be washed away by the water jets.

§ 120. SCREW PILES.—The screw piles used in the construction of large bridges and piers, generally consist of hollow cylinders of cast iron, or solid bars of wrought iron or mild steel. At the foot of the pile there is a helical flange carried nearly once round the pile, or for very soft soils once and a half or twice round in a spiral. The pitch or vertical distance gained in one convolution may vary according to the soil penetrated, but the general practice is to adopt a mean pitch of between 6 and 10 inches, according to the resistance to penetration.

The diameter of the screw blade (see figure 56, page 140) is generally from 2½ to 3½ times the diameter of a hollow pile, and from 6 to 8 times that of the solid pile.

The cast iron hollow pile varies from 8 to 24 inches in diameter, though larger piles are used ; the solid pile may be from 3 to 8 inches in diameter, according to the size of rolled bar iron procurable.

FIG. 56.

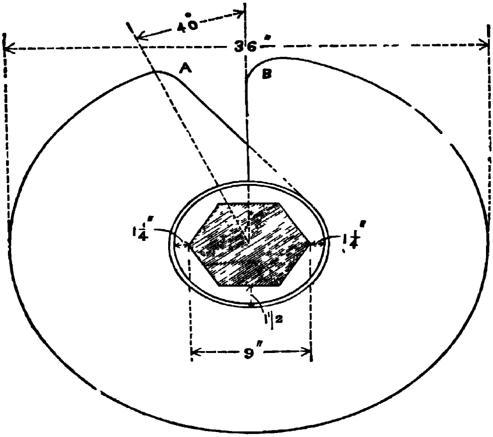


FIG 57.

Scale = $\frac{1}{12}$

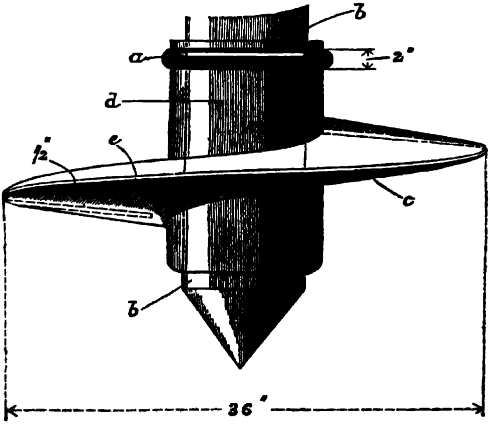


FIG. 58.

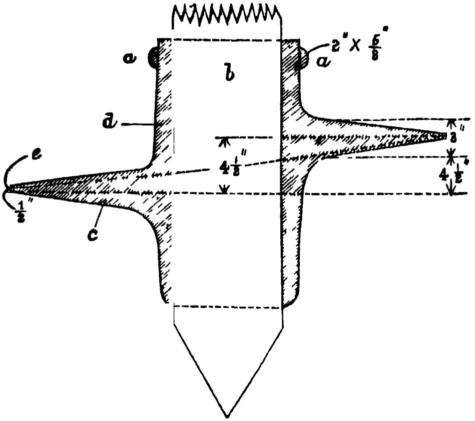


Figure 56 is the plan of a screw blade, the lower or cutting edge A *being tangential, and the upper or following edge* B *being radial to the pile. The shaded portion in the middle of the figure shows the hexagonal wooden pile in cross section, so as to take the torsional stress of screwing down the pile.*

The minimum thickness of the casting is 1¼ inches, and this is increased by 25 per cent. where the screw blade is carried. The angle measured horizontally between the two edges of the screw blade is 40°. (Scale = 1/12.)

Figure 57 shows the screw pile casting in elevation, and figure 58 is a vertical section through the same. The cutting edge shown in figure 57 (dotted where not visible) is ½ inch thick. The thickness of the blade (see figure 58) where it is united to the socket into which the pile fits is a little more than 3 inches thick.

The pitch of the screw is 9 inches, the half pitch is shown in figure 58. The band a shrunk on to the socket near its upper end is 2 inches wide by ⅝ inch thick, b is the wooden pile, c is the blade, d the socket casting into which the pile is fitted and rivetted (the rivets are not shown in the figures), c is the cutting edge of the screw blade. (Scale = 1/12.)

In the cast iron hollow pile the screw blade forms an integral portion of the casting; the metal is thickened by about 25 per cent. where the screw blade is carried, and also at the flange and at the spigot and socket joints.

For the solid pile a separate mild steel or iron casting is made, to fit on the lower end. The casting may be a short length of hollow cylinder carrying the screw blade; the solid pile penetrating through the casting and terminating in a blunt point: or the casting may be socketted, and terminated in an auger point. In each case the torsional stress of screwing down is taken by a flat surface planed on the side of the pile, (or two opposite flat surfaces) fitting on to a similarly shaped passage or socket in the casting; a through rivet holds the casting on the pile end. The lip of the socket should be reinforced by wrought iron hoops shrunk on.

In localities where the cost of transport renders the use of cast or wrought iron or mild steel piles impracticable, screw piles are made of hard tough wood, square in section, furnished with a cast iron screw point; the wooden pile may penetrate through the casting and end in a blunt point, or the casting may be socketted and terminate in a sharp point; the wooden pile being fastened by two rivets, placed at right angles to each other, to the socket of the casting, as is done in the case of disc piles.

The screw blade for ordinary compact earths is carried less than one turn round, and its edges do not overlap (see figure 56, page 140).

The lower or cutting edge of the blade is designed tangential to the outside of the pile, and the upper or following edge starts from nearly the same vertical line, but is radial to the pile, as shown in figure 56, page 140. The angle between the two edges on the plan is about 40 degrees. There is a clearance therefore between the edges, facilitating the passage of the blade through the earth.

§ 121. The screwing down or rotation of the pile may be effected by manual, or animal power, applied to long lever bars lashed, or otherwise fastened to the pile; the power thus obtained for rotating the pile is generally sufficient to screw it down in light soils. In one instance 4 oak levers 24 feet long, bound round with hoop iron, were fitted into sockets in a disc capstan-head, mounted rigidly on the top of the pile, a horse being attached by a chain to the end of each lever. In another case, eight lever bars, each 9 feet long, were shipped in a cast iron capstan-head mounted on the pile. The bars were probably 4½ inches by 4 inches at the periphery of the capstan and 3 inches diameter at the extreme ends, and 3 men pushed at each lever bar, which should be of good sound, straight-grained, tough wood. Long levers give more power, and examples are on record of lever bars 20 feet long with 5 or 6 men to each bar, and of bars 40 feet long, eight bullocks being yoked to each of the four levers.

The capstan-head may conveniently be made of two annular discs of wrought iron plate 3½ feet to 4 feet external diameter, and ½ to ⅝ inch in thickness, separated by wedge-shaped blocks of hard wood, placed radially and equidistant, and fitted between the discs so that 6 or 8 sockets are formed to receive the ends of the capstan bars (see figures 59 and 60, page 144; and 61 and 62, page 146). The discs are rivetted or bolted through the wood blocks, and three or four of these fastenings may be eye bolts, for the attachment of ropes or chains, by which the capstan-head can be lifted. Annular disc capstan-heads have generally an octagonal or hexagonal central aperture, a cast iron socket of corresponding shape being fitted between and bolted through the discs. The head of the pile is cut to a similar shape and the capstan-head fits tightly on to it.

FIG. 59.

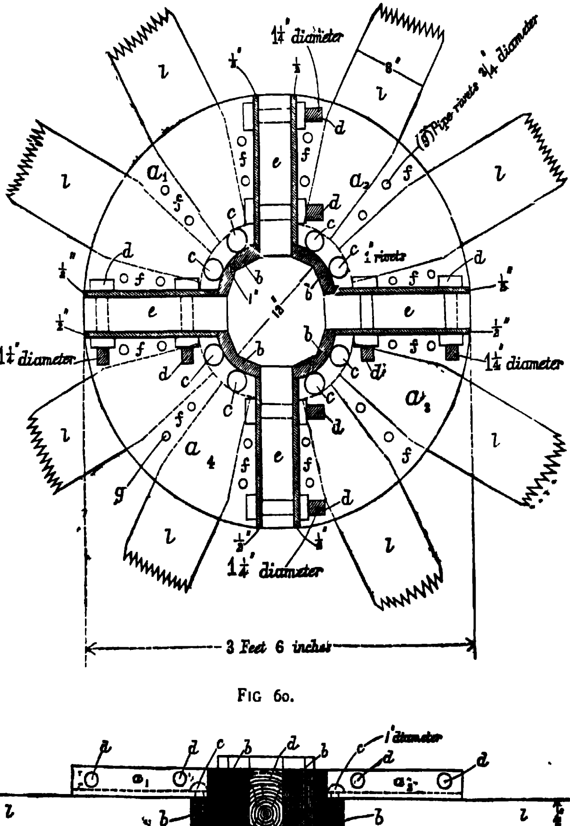

l
l
l
l
l
l
l
l
$1\frac{1}{4}$" diameter
$\frac{1}{2}$"
$\frac{1}{2}$"
8"
(g) Pipe rivets $\frac{3}{4}$" diameter
d
f
e
f
a_1
a_2
f
f
d
c
c
c
c
1" rivets
b
b
1"
13"
d
d
$\frac{1}{2}$"
$\frac{1}{2}$"
f
f
e
e
$\frac{1}{2}$"
$\frac{1}{2}$"
f
f
b
b
$1\frac{1}{4}$" diameter
$1\frac{1}{4}$" diameter
d
d
c
c
c
c
d
a_3
f
f
e
f
a_4
d
g
$\frac{1}{2}$"
$\frac{1}{2}$"
$1\frac{1}{4}$" diameter
3 Feet 6 inches

FIG 60.

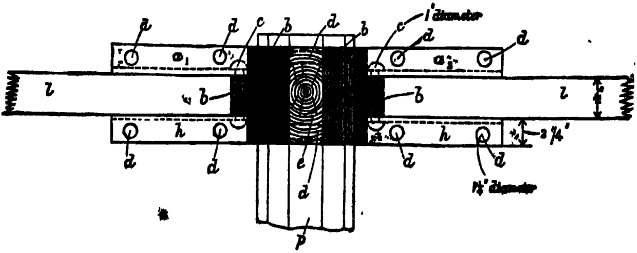

d
d
c
b
d
b
c
1" diameter
d
d
a_1
a_2
l
b
b
l
h
h
3/4"
d
d
d
d
e
d
$1\frac{1}{4}$" diameter
p

Figure 59 is the plan of a capstan-head made of two wrought iron plates rivetted on to a central cast iron socket, the internal section of which is octagonal.

Each of the wrought iron plates, as well as the central cast iron socket, is made in four equal sections. a_1, a_2, a_3, a_4 *are the 4 sections of the upper wrought iron plate (those constituting the lower plate are not seen in the plan) and b, b, b, b the sections which make up the central cast iron socket. The sections* a_1, a_2, a_3, a_4 *are made of ½ inch wrought iron plate, the thinnest part of the cast iron socket is one inch. The cast iron socket is seen in cross section in figure 60. The sections b, b, b, b are fastened, each by two rivets (c c) one inch in diameter, to the corresponding sections of the cast iron central socket.*

The four sections a, a, a, a are bolted to each other by bolts d, d, 1¼ inches in diameter, two bolts being required for each junction. When the sections a, a, a, a are in contact with one another, the diameter of the central aperture, which is fitted on to the top of the pile, is 8 inches. Blocks of wood e, e, e, e can be placed between the several sections so as to increase the diameter of the central aperture to twelve inches. The bolts d, d, etc., pass through the blocks of wood e, e, e, e. Other blocks of wood f, f, f, f, etc., are placed at intervals, as shown in the figure, between the upper and lower plates, and are fastened to both plates by rivets placed in iron pipes g, g let into the plates (to prevent the wood being burnt). The blocks f, f, f, etc., form holes into which the ends of the levers l, l, l, etc., by which the capstan is rotated, are placed. The portions of the socket and wrought iron plates which are seen in cross section are marked with cross lines. The portions of the levers, central socket, and bolts which are not seen are shown in dotted lines. (Scale= $\frac{1}{18}$*.)*

Figure 60 is an elevation of one-half of the capstan-head, the section a_3 *and* a_4 *having been removed. The letters are those used in figure 59, b, b, parts of the central socket, are seen partly in elevation, partly in section, h, h are sections of the lower plate which is not visible in figure 59. d, d, d, d, etc., are either rivet holes or else rivets. p is the upper part of the pile which is to be screwed down. (Scale=* $\frac{1}{18}$*.)*

§ **122.** A hand driven windlass, single or double purchase according to the power required, may also be used for the rotation of a screw pile. A stout rope is wound several turns round the deepened ends of the arms of a strong capstan-head rigidly fixed on the pile (see figs. 61 and 62, page 146) ; the rope passes at one end to the drum of the windlass, and as the rope is wound on the drum, it causes rotation of the capstan-head and pile ; when the rope is entirely unwound from the capstan-head, it must be again coiled round it and the same process repeated.

FIG. 61.

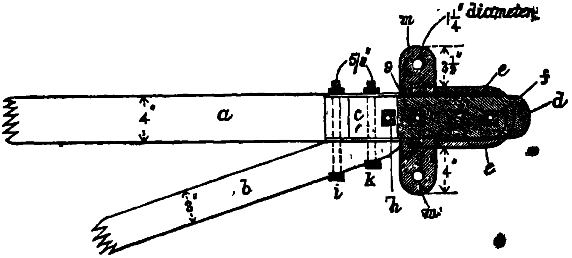


FIG. 62.

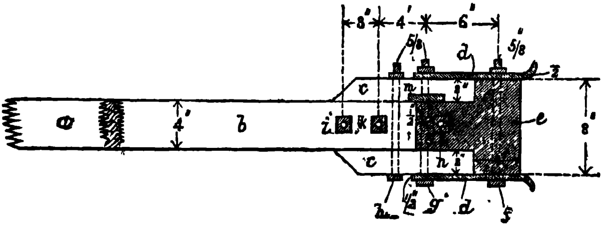


Figure 61 shows in plan and fig. 62 in elevation, the detail of the end of one of the arms of a strong capstan-head, rigidly fixed to a pile which can be rotated by means of a rope and a single or double purchase windlass.

a is the end of the arm (capstan bar) c, c are two small blocks of wood, placed one above and the other underneath the end of the capstan bar so as to deepen it and are bolted (h, g and f are the bolts) to it. e is a thin plate of metal bolted (n is the bolt, not seen in elevation) on to the enlarged end of the arm to protect it. The plate m is bolted on to the top of the bar, and the chains which brace adjacent pairs of levers are attached to these plates. The bars are strengthened by struts b, b bolted on to the ends of the arms (i and k are the bolts) and abutting against the next lever where it leaves the capstan-head. d, d are thin plates bent up at the end as shown in fig. 62 which keep the coiled rope from slipping off the end of capstan bars. (Scale = $\frac{1}{12}$.)

Continuous rotation may be secured by the use of an endless rope taking one turn round the grooved ends of the capstan bars mounted in the capstan head, and two or three turns round the drum of the windlass. The capstan bars may be 9 inches by 4 inches at the periphery of the capstan-head tapering in about 10 feet length to 5 inches by 3 inches; at their grooved outer ends they are fitted with wrought iron collars, to which are attached chains, with coupling screws between each adjacent pair of bars, so that the ends of all the bars can be braced rigidly together; the chains may be of ½ inch round wrought iron and the right and left handed coupling screws ⅞ inch in diameter, the screw links of ⅝ inch round bars. The total diameter of the capstan-head with the bars may therefore be about 23 feet. The endless rope must be guided on to the capstan bars and on to the windlass drum by sheaves fixed at convenient points; a man is usually employed to dispose of the rope as it comes away from the drum.

§ 123. It is necessary to use strong guiding tackle to prevent the screw pile from swerving out of its true position. An ordinary form consists of a wrought iron ring, built up of 4 or 6 segments flange bolted together, and fitting loosely round the pile; this ring can be fixed in position to guide the pile by ropes or chains extending to convenient fixed points. In some cases the ring encircling the pile may be rigidly fixed to a beam which extends between two fixed points.

The carrying power of a screw pile, or of any pile driven into soft ground, may be increased by placing round the pile, two or three layers of stout logs, round or roughly squared, each layer crossing joints with the previous one. A strong casting with a wide flange at its lower end, built up of two halves, by bolted flanged joints at a vertical division, is fitted closely gripping the pile, and also resting firmly on the timber logs, thus transmitting the load on the pile to the log platform covering a large area of the surface of the ground. The casting may with advantage be placed so that its upper end abuts against a block of wood notched and bolted or spiked to each side of a timber pile.

§ **124.** In the case of the timber bridge constructed over the Rohini torrent in the Darjeeling Terai, a stream which flows through and over a bed of large boulders and gravel and sand, and is dry or nearly so in the winter and hot weather, and subject to sudden floods during the rains; Mr. Manson, then Deputy Conservator of Forests, adopted the following expedient. The wooden beams, of which the piers were constructed, were first framed and bolted together, trenches were excavated for each pier when the river was almost dry shortly before the commencement of the rains, and the framed piers were placed in the trenches, and firmly embedded in them. This bridge has stood for 15 years and none of the piers have been washed away, though several heavy floods have occurred which have cut through the embankments at either end of the bridge. Mr. Manson had observed that bridges built on piles in streams, were frequently broken by the stream cutting a deep channel in one place, and washing out the piles of one or more piers, and also that there much difficulty was often experienced in driving piles into the beds of streams, owing to the abundance of the boulders, and that the workmen cut off that portion of the pile that they could not drive into the bed of the stream.

§ **125.** When a bridge is to be taken across a depression, down which no considerable volume of water ever flows, the piers which support it, may be constructed of *dry rubble* stone work, strengthened if necessary at intervals, by horizontal frames of wood notched on to each other. These piers should be rectangular or square in plan, the sides being built tapering upwards with a batter of 1 in 6 or 1 in 8. The top of the pier should be sufficiently wide to carry the roadway of the bridge. The construction of a pier of this description is shown in Volume I, Part II, figure 88, page 171.

Where stones suitable for dry rubble are not available cribwork piers and abutments may be constructed. A cribwork, pier consists of a framework of rough poles, fastened to each other by wooden pegs or nails, and filled with stones. The poles are arranged so that the stones inside cannot be washed out by the force of the stream to which they are exposed.

The construction of cribwork piers is similar to that of cribwork spurs, and will be discussed in detail in Volume III, Part VII.

§ 126. THE LONGITUDINAL BEAMS —Under ordinary circumstances no truss is required to strengthen the longitudinal beams over a span of less than 20 feet, and where timber of large dimensions is available, the span may be increased to 30 feet for bridges on inspection or bridle paths or sledge roads. Figure 63 shows the arrangement of the longitudinal beams in such a case

FIG. 63

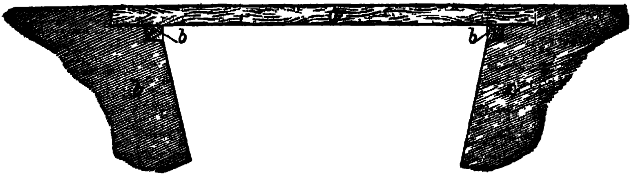


Figure 63 shows in elevation the longitudinal beam of a simple wooden bridge before the roadway has been added. a is the longitudinal beam; b, b the wall plates. c, c the abutments of the bridge. The other longitudinal beams are not visible.

The ends of the longitudinal beams should rest on scantlings called *wall plates*, laid either on the abutments of the bridge on either side of the obstacle to be spanned, or on wooden posts which may take the place of the abutments in the case of bridges of a small span, or on footpaths. The wall plates distribute the weight of the structure more uniformly over its supports.

If the abutments are constructed of masonry, and large slabs of stone are available, they should be used in preference to wooden plates, as they are more durable.

The dimensions of the longitudinal beams depend upon the live and dead load which they have to carry and also upon the span (see §141, page 167).

The roadway of foot bridges usually rests on two longitudinal beams, placed parallel to each other and carrying the transverse planks of the footway.

As regards bridges for cart-roads just wide enough for the passage of one cart, if two longitudinal beams only are used, they should be arranged, if practicable, so as to fall under the wheels of the cart. If three or more longitudinal beams are used, they should be placed at equal distances from each other.

If the available beams are too short, and the longitudinal beams have to be constructed of two beams, the joints should, whenever practicable, be made over a permanent support.

§ 127. The scantlings used for the longitudinal beams of bridges are usually rectangular in section, and are laid on one of the narrower sides. In rough forest bridges, in localities where wood is plentiful and labour expensive, it is often economical to use roughly squared instead of rectangular beams.

The sectional area of beams, square in section, required to support a given weight, will be greater than that of properly dimensioned beams rectangular in section; but where timber of a large size is plentiful, this is practically of little importance.

The strongest beam[1] that can be cut out of a log is obtained by dividing its diameter *A C* (fig. 64) into three equal parts at 1, 2, and drawing perpendiculars at these points at right angles to *A C* to meet the circumference of the log at *B* and *D* and joining the points *A B C D.*

The stiffest beam, *i.e.*, the beam which will carry the greatest weight with the least bending, will be obtained, if the diameter is divided into four parts instead of three, as has been done in fig. 65, and joining the points up as in the first example.

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[1] Molesworth's "Pocket-book of useful Formulæ and Memoranda for Civil and Mechanical Engineers," 21st edition, 1882, page 121.

FIG. 64.

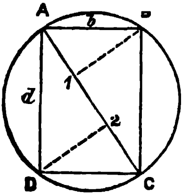

FIG. 65.

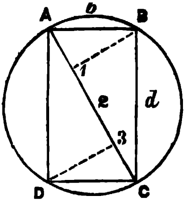

Figure 64 shows the method of cutting the strongest beam possible out of a log $b : d :: 0{\cdot}7 : 1{\cdot}0$.

Figure 65 shows how the stiffest beam (against transverse bending) may be cut out of a log, in this case $b : d :: 0{\cdot}57 : 1{\cdot}0$.

§ 128. TRUSSED BEAMS.—For a span of more than 20 feet it may be difficult in the case of a bridge on a cart-road, to obtain beams of the size required to carry the weight of the superstructure of the bridge, and the live load which will pass over it. The beams will generally be found to be insufficiently deep. A beam may be strengthened by increasing its depth in the manner shown in fig. 66, by bolting two beams together, wooden keys (*b b*, Fig. 66) being introduced between the bolts, to prevent the different parts from sliding one over the other. These keys should be of hard wood. The total

FIG. 66.

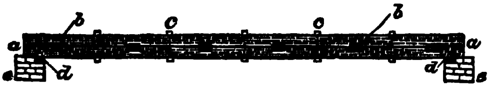

Figure 66 shows in elevation a method of making a large beam out of two smaller ones, by bolting them together. Keys are added to prevent one of the beams sliding over the other; a a are the two small beams; b b the keys; c c the bolts placed at equal distance along the beam; d d the wall-plates, and e e the walls on which the beam rests (after Tredgold).

thickness of all the keys used should be somewhat greater than $\frac{4}{3}$ of that of the resulting beam, and their total breadth twice that thickness.[1]

§ **129.** Tredgold[2] gives the following rule for determining the dimensions of the iron rod used when the beam is trussed as shown in fig. 67. The depth of the truss being $\frac{1}{12}$th of that of the span, and the horizontal portion $C\ D$ being $\frac{1}{3}$rd of the span, the diameter (d) of the horizontal portion $C\ D$ and (d) of the parts $A\ C$, $D\ B$ *in inches* are given by the formulæ

$$d = 0{\cdot}13\sqrt{w} \text{ and } d_1 = 0{\cdot}15\sqrt{w}$$

respectively, where w = weight which the beam has to support added to half its own weight expressed *in cwts.* (1 cwt. = 112 lb.)

FIG. 67.

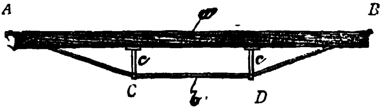

Figure 67 shows a method of strengthening a beam by the addition of an iron rod and brackets; a is the beam; b the iron rod; c, c the bracket (after Tredgold).

Iron plates or large washers should be placed on the cut surfaces of the beam at A and B, to prevent the wood being crushed by the nuts which keep the rod b in position. The cut surfaces themselves should be at right angles to the directions of those portions of the rod which pass through the beam itself.

§ **130.** Figure 68 shows a method of strengthening a longitudinal beam, by decreasing the distance between the points at which it is supported, and also an ingenious method of supporting a wall plate when the material of which the abutment is composed is wanting in strength. Both these contrivances have been used by Mr. F. A. Lodge, Deputy Conservator of Forests in the Madras Presidency, and are likely to be of use to Forest Officers in other parts of India.

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[1] Tredgold's "Carpentry," by Hurst, 4th edition, London, E. and N. Spon., 1883, page 135.

[2] Tredgold, *op cit.*, page 177.

FIG. 68.

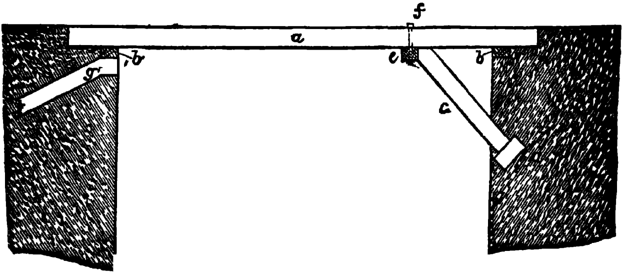

Figure 68 shows in elevation on the right hand side, a method of strengthening a longitudinal beam by decreasing the distance between the points at which it is supported and on the left-hand side, a method of supporting a wall plate when the material of which the abutment is constructed is wanting in strength. a is in longitudinal beam b b the wall plates on which it rests, g one of the inclined beams by which the wall plate is supported. Two or three such beams should be used to support the wall plate. c is a strut which is added to form an additional point of support to the longitudinal beam. Its upper end rests against a block of wood bolted e (or strapped) to the longitudinal beam, while its lower end rests on a stone slab, d, placed as shown in the figure, f is the bolt which fastens the block e to the longitudinal beam a. A strut similar to that shown in the figure is placed under each of the longitudinal beams of the bridge.—(Drawn by I A Lodge)

§ 131. Where iron is not available, or where sufficiently long beams cannot be obtained, the longitudinal beams may be supported by inclined struts as in figure 69, page 154. A strutted beam can be used for spans up to 50 feet in length.

The longitudinal beams A and B are supported by a straining beam C D, the two lengths are joined by a simple butt joint (see figure 69, page 152), the ends being bolted or strapped to the straining beam. The free ends of the longitudinal beams rest on wall plates I and K, which are in their turn supported by the abutments of the bridge. The straining beam is supported by two inclined struts E and F, the lower ends of which rest on wall plates

G and H, or stone blocks (fig. 68, page 153) built into the piers or the abutments of the bridge. A plain mitre joint should be formed between the straining beam and the struts, and iron straps (see figs. 75 and 76, page 160) added to prevent lateral motion if the struts are inclined at an angle of less than 45 degrees with the horizon. These straps should be placed one on either side of the straining beam and strut to be joined together and should be bolted together through them. (See figs. 75 and 76, page 160).

The ends of the struts E and F are shown in figure 69 as cut off so as to rest on horizontal beds; they are stronger if their ends are squared, and rest on wall plates placed at right angles to their length—(*F. A. Lodge*); but in this case induce a great thrust on the abutment.

The struts may be tied together by scantlings placed horizontally (*braces*) nailed on to the struts to prevent their spreading laterally. (See fig. 77, page 161.)

If the struts which support the straining beam are long, they may be braced (*e*, fig. 77, page 161) to the main longitudinal beams of the bridge to prevent their *sagging*, that is, bending downwards in the middle of their length. The construction of this truss will be considered in detail later on, see § 136, page 160.

FIG. 69.

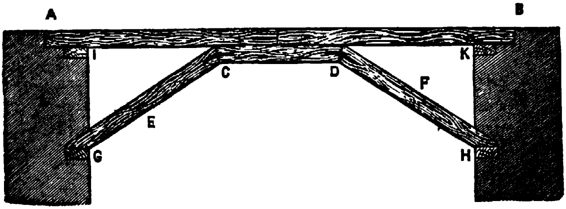

Figure 69 shows in elevation a longitudinal beam of a bridge of a greater span than 20 feet, when no long timber is available. A B *the longitudinal beam which is in two parts;* C D *is the straining beam which strengthens the joint;* E, F *are struts supporting the longitudinal beams and abutting against the ends of the straining beam;* G, H, I *and* K *are wall plates;* L *and* M *represent the abutments of the bridge.*

§ **132.** In the case of footbridges on inspection or bridle paths, where the span is more than 20 feet, a simple T-shaped support, shown in figs. 70 and 71, may be introduced, lessening the span according to the number and position of the supports.

FIG. 70.

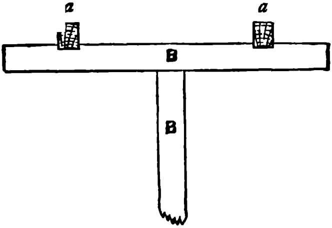

FIG. 71.

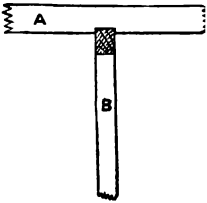

Figure 70 is the end elevation of a simple T-*shaped support for foot-bridges. a, a are the longitudinal beams of the bridge; B is the* T-*shaped support.* (*Scale* = $\frac{1}{32}$.)

Figure 71 is the side elevation of the same support. B *is the longitudinal beam;* A *the support.* (*Scale* = $\frac{1}{32}$.)

The weight which a beam of given dimensions can carry safely depends, among other considerations, upon the distance between the points at which it is supported. The greater the distance between the points of support, the smaller will be the load that it can carry : in the case of the longitudinal beam of a bridge, the introduction of an intermediate support decreases the distances between the points at which the longitudinal beam is supported, and consequently allows of the beam supporting a load which it could not otherwise carry.

The support need not necessarily be placed at the centre of the span, but should have a firm foundation, and should be placed where it will not be carried away by the stream. Where the bridge is not used in the rains, the support may be removed as soon as the rains set in.

§ **133.** Sometimes scantlings sufficiently long to stretch across the obstacle to be spanned cannot be obtained, and two scantlings must be joined together so as to make a beam, of the required length. If the beam cannot be strengthened by the introduction of an intermediate support, the joint must be a scarfed one, specially constructed so as to resist a cross strain (see Volume I, page 110, figs. 32 and 33).

If the joint, however, can be directly supported, a much simpler form may be adopted, as shown in figure 72, page 157. A T-shaped support must be placed under each beam that is joined and if it is considered advisable, these supports may be stiffened by being tied to each other by inclined braces.

The joint need not necessarily be placed in the middle of the span, but should be put in any position where a good foundation can be obtained for the support which strengthens it.

FIG. 72.

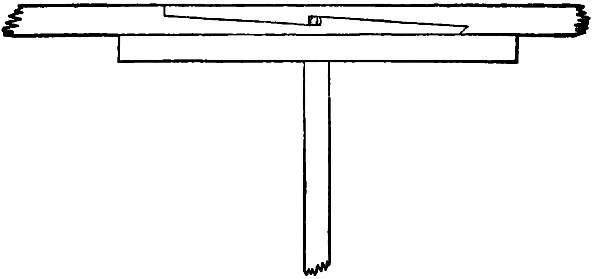

Figure 72 is a side elevation of a support to be placed underneath a longitudinal beam which has been lengthened by scarfing, in the case of a soft straight grained wood, such as a conifer. (*Scale* = $\frac{1}{24}$.)

§ **134.** On an inspection or bridle path, a sledge road, or even a cart-road, when the stream to be bridged is subject to floods, and a rush of water might carry away the struts or other form of support placed below the roadway, a truss may be constructed above the roadway of the bridge as is shown in fig. 73, page 158. Where the roadway of the bridge can be supported on two longitudinal beams, placed one on either side of the roadway, as, for example, in the case of a bridle path or sledge road, the cross pieces which support the roadway itself can be laid directly on the beams *f*. In this case the beam *i* is not required and can be omitted altogether.

FIG. 73.

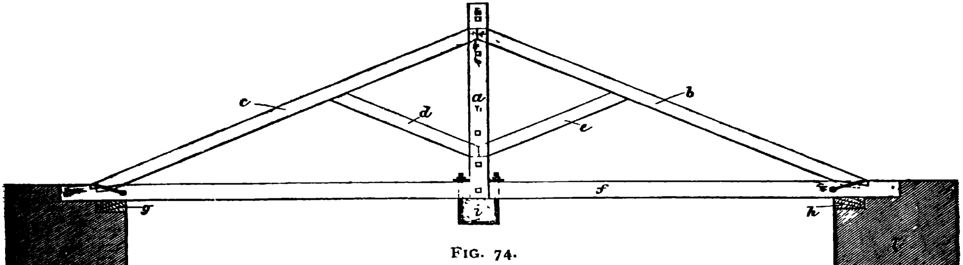

FIG. 74.

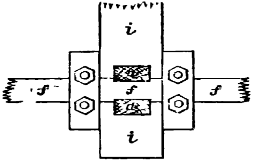

Figure 73 is an elevation of a truss placed above a bridge, one on either side of the roadway of a bridge on a cart-road. a is a suspending piece (for details of which see figures 46, 47, page 117, Volume I). The upper ends of the long struts b and c, and the lower ends of the short struts d and e rest on wooden blocks, placed between the two scantlings which form the suspending piece. The lower end of the suspending piece is bolted through the longitudinal beam f of the bridge. g and h are wall plates. A central longitudinal beam is carried by the cross-piece i. This cross-piece is fastened to each outer longitudinal beam by two wrought iron stirrups which are bolted through two iron plates resting on the top of the longitudinal beam f, and placed one on either side of the suspending piece a. a. k and l are the abutments of the bridge. (*Scale* = $\frac{1}{32}$.)

Figure 74 is the plan of the joint between the longitudinal beam of the truss and the cross-piece. The same letters are used as in figure 73.

The iron plates are seen in this figure in plan, as are the heads of the straps and the bolts which fasten them to the iron plates. (*Scale* = $\frac{1}{16}$.)

For the details of the construction of this truss reference should be made to Volume I, Part I, section IX, paragraphs 95, 98, 101, pages 114, 117 and 125, where the different forms of joints are discussed in detail.

§ 135. CONSTRUCTION OF A STRUTTED BEAM.—In a strutted beam scantlings which have to resist a force of compression are called *struts*, and those which are subjected to a tensile force are called *ties* or *braces*.

Joints in timber construction are a source of weakness, they must be made as strong as possible; and the simpler the joint the easier is it to make accurately and well fitting. The surfaces of the wood forming the joints should be in perfect contact, so that pressure is transmitted uniformly. If the surfaces of the wood are ill fitting, the parts in actual contact will bear the pressure intended to be carried by the whole area of the joint; this may induce a splitting or crushing of the fibres of the wood.

Some of the joints, for example, that between the straining beam and the struts, may be further strengthened by the addition of iron straps placed one on either side of the beam (figures 75 and 76, page 160), and fastened to it by bolts.

The size of the iron straps used will vary with the dimension of the beam to which they are applied. Straps two feet long two inches wide and ¼ to ½ an inch thick will usually be sufficient for ordinary trusses.

FIG. 75.

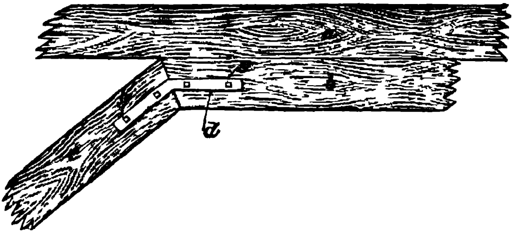

FIG 76

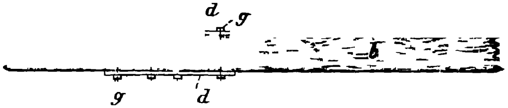

Figure 75 shows in elevation an iron strap, used to strengthen the mitre joint between a straining beam and a strut. a is the longitudinal beam, b the straining beam, c the strut, d is the strap. g, g the bolts by which it is fastened to the straining beam and the strut. (Scale = $\frac{1}{24}$)

Figure 76 is a plan of the strut and the straining beam the longitudinal beam having been omitted. Letters used are the same as in Fig 75. (Scale = $\frac{1}{24}$)

§ 136. CONSTRUCTION OF A TRUSS.—The longitudinal beams will be laid as described in § 126, page 149.

The straining beam should be of the same dimensions as the longitudinal beam, and its length about a third of the span. The struts supporting the straining beam should be rectangular, their breadth being equal to that of the straining beam they support; the depth of the struts will vary with their inclination to the horizon.

FIG. 77.

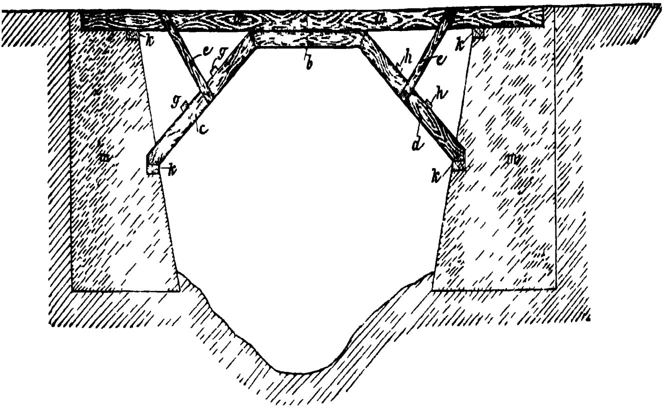

Figure 77 is a side elevation of a strutted longitudinal beam suitable for bridges up to 50 feet span a a are the longitudinal beams, b the straining beam c d the struts, e e g g, h h braces k k k, k wall plates, m, m abutments built on rock The bolts and straps used in the construction of the various joints have been purposely omitted.

If the length of a strut (*c*, *d*, fig 77) is more than eight times its depth, it should be strengthened by a tie (*e*, figure 77), suspending it from the longitudinal beam above.

The angle of inclination of the struts *c*, *d*, to the horizon may be from 40 to 60 degrees, and is usually 45 degrees. If sufficient waterway cannot be obtained without making this angle less than 45 degrees, then the joints between the struts and the straining beam should be strengthened with straps as shown in figures 75 and 76, page 160.

The ways in which the lower ends of the struts may rest has been discussed in §§ 130, 131, pages 152, 153, to which reference should be made.

The trusses which support the individual longitudinal beams of the bridge may be tied together (figure 77, page 161) by horizontal pieces of wood *g*, *h* in order to prevent their spreading abroad, and thus endangering the stability of the structure.

All wall plates should be visible, so that they may be replaced before their decay endangers the stability of the bridge. Stone blocks are more durable than wooden wall plates.

§ 137. PREPARATION OF THE WOOD USED IN BRIDGE BUILDING.—The preparation and preservation of wood has already been considered in Volume I, Part I, Section VI, page 58 *et seq.*, so very few additional remarks will be required here.

If possible, the trees from which the scantlings are to be obtained, should be felled or girdled a full year before the timber is required, in order to allow the wood to season. No appreciable quantity of sap-wood should be allowed to remain on the beams, struts, or ties, when the bridge is constructed of sawn timber. Tar or paint materially increases the durability of the wood, provided that it is thoroughly seasoned; where wood-tar can be made locally, it may be applied with advantage. As a rule, the additional cost of tar or paint renders their use impracticable in the case of ordinary forest bridges; it is usually found cheaper to renew the timber portion of the bridge when required, rather than to use expensive preservatives in the first instance.

The ends of beams or posts buried in the ground should be well charred and tarred to protect them from attacks of fungi and insects. The portion thus coated should extend at least 6 inches above the ground; beams and posts are very liable to decay at the surface of the ground.

§ 138. THE ROADWAY OF A BRIDGE.—The roadway of a wooden bridge is generally constructed of planks. The planks are usually fastened directly to the longitudinal beams, and are then arranged at right angles to the direction of the road.

If cross beams are laid on the longitudinal beams, the planks may then be placed either diagonally to, or parallel to, the direction of the road.

If the planks are laid diagonally, the weight of a cart or laden animal will be supported by a larger number of planks, and each plank will consequently have to support a smaller weight, which is often a decided advantage.

If the planks are laid parallel to the direction of the roadway, a portion of the bridge can be taken up at a time and those planks which are worn away by cart-wheels can be renewed without taking up and renewing the whole of the roadway.

If the roadway of the bridge on a cart-road is supported on 2 or 3 longitudinal beams only, the bridge will be much stronger, if cross beams are placed on the longitudinal ones, and the planks of which the roadway is made, fastened to the cross beams.

The planks in the case of bridges on cart-roads may be, or may not be, covered with broken stone or earth.

Sometimes in foot-bridges, an additional layer of thin planks is laid along the centre of the roadway of the bridge to save wear and tear, as the greater part of the traffic passes over that portion of the bridge. These small planks can be renewed when worn out, without necessitating the removal of the whole of the roadway of the bridge.

A roadway made of planks only, is much lighter than one which is covered with broken stone ; and is generally preferable except where the traffic is heavy. A quarter to half inch space should be left between each plank, so as to allow rain-water to run off quickly and also for the swelling of the wood in wet weather. The thickness of the planks will vary from 1½ to 3 inches with the nature of the traffic and the width of the roadway.

In Chittagong bamboos are used instead of planks in the construction of the roadway of small bridges. The bamboos, slit at the joints and flattened out are woven like a mat, and laid on the beams (which are placed rather close together) and covered with sods of turf; a very good roadway is thus formed. Sometimes two or more thicknesses of this bamboo matting are used. Bamboos similarly flattened out, but not interwoven, are used in the construction of the roadway of temporary bridges on the Teesta Valley Cart-road (Darjeeling district).—(*F. B. Manson.*)

§ **139.** THE RAILING.—A strong railing, about 4 feet high, made either entirely of wood or of wooden uprights, with two lines of wire instead of wooden battens, should be placed on either side of the roadway for the protection of the traffic. The construction of such a railing is shown in figs. 78 and 79. The uprights may be tenoned into cross pieces (*a*, fig. 78) placed at suitable distances (about 6 feet apart), or else notched into and nailed on to them. A stronger construction is to have the cross piece (*a*) in two parts, make a tenon at the lower end of the upright (*b*), place it between the two parts of the cross piece, and nail or bolt the three pieces of wood together. The upper end of the strut (*d*, fig. 78) should in this case be nailed to the upright, and its lower ends placed between, and nailed to the two parts of the cross piece.

FIG. 78.

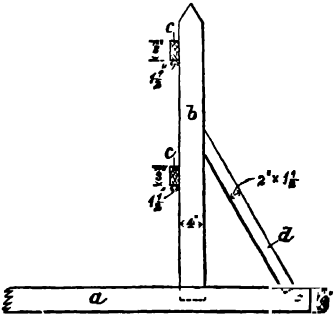

Figure 78 is a section through a wooden railing suitable for a bridge or path: a is the cross-piece to which the upright post of the railing is fixed: b is the upright or post; c, c the railing which is fastened to the posts by strong iron staples. The individual rails abut against each other on a post. d is a strut added to strengthen the upright. (*Scale* = $\frac{1}{16}$.)

FIG. 79.

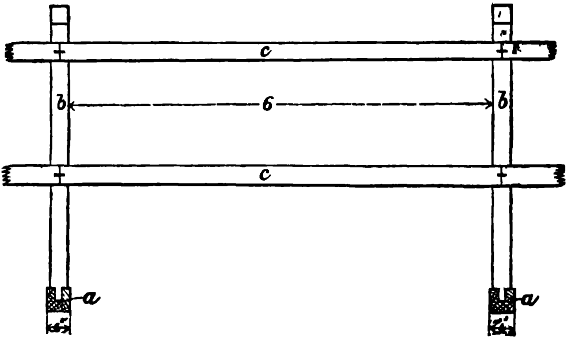

Figure 79 is the inside elevation of the same railing the struts are hidden by the uprights and are not seen in this figure (Scale = $\frac{1}{24}$)

The uprights should in any case be strutted, adjoining planks may project outside the railing in order to receive the feet of the struts; or small tranverse beams may be introduced at intervals for the same purpose. These beams, if thicker than the planking, may be notched on to the longitudinal beams to keep the road surface level.

If wire is substituted for wooden battens, it may be kept tight by using the galvanized straining eye bolts shown in figure 80. The bolts are made of diameters of $\frac{3}{8}$, $\frac{1}{2}$ and $\frac{5}{8}$ inch and of lengths of 9, 12, 15 and 18 inches and are now in general use in Europe.

FIG 80

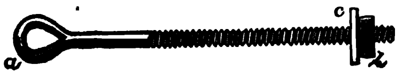

Figure 80 is a sketch of a galvanised straining eye bolt used for tightening wire railings. a is the eye-bolt, b the washer, circular in plan, and c a nut which works on the thread of the bolt.

The wooden battens or wires which form the railing may pass through the uprights, or else be fastened to them on the inside.

If wooden battens are used, they should be fastened to the inside of the uprights, because if holes are cut in the uprights to receive them, the latter are necessarily weakened.

§ 140. ROAD GALLERIES.—It occasionally happens that a road has to be carried along the face of a cliff, and in this case a gallery is necessary. Figures 81 and 82 taken from the "Roorkee Treatise on Civil Engineering" will explain the principle upon which such galleries are constructed. The scantling of the beams used may be calculated in the same way as in the case of bridges.

FIG. 81.

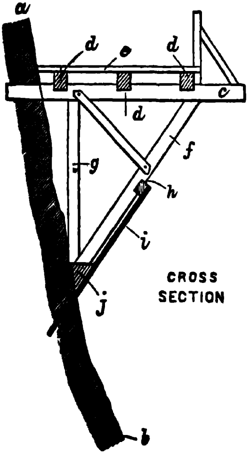

FIG. 82.

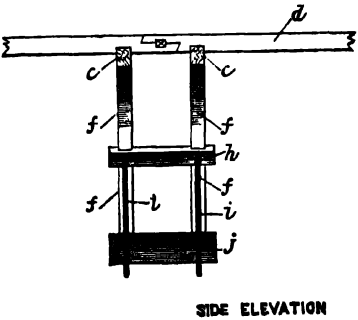

Figure 81 is a cross-section, and 82 a side elevation of a cliff gallery. a, b is the side of the cliff; c, c are the cross pieces of the truss, upon which the longitudinal beams d, d, d, which carry the planking e of the road gallery, rest; f, g are the parts of the truss which support the roadway; h is a tie to stiffen the truss; j is a footing of wood upon which the lower ends of f and g rest; while i, i are iron rods supporting the footing j (after the Roorkee Treatise).

§ 141. CALCULATION OF THE DIMENSIONS OF THE SCANTLING OF THE TIMBERS USED IN A WOODEN BRIDGE.

Breaking weight.—If a sufficient weight be applied to the centre of a beam supported at both ends, the beam will bend and, ultimately, if the weight be sufficiently increased, will break. The greater the distance between the points of support and the smaller the dimensions (especially the depth) of the beam, the less will be the weight which is required to break it. The weight, applied at its centre, which will break a beam, is called the *breaking weight* (see Volume I, page 88). The actual *amount* of the weight required to break a beam, in any special case, depends upon the depth and width of the beam experimented on ; and on the distance between the points at which it is supported, as well as the quality of the timber. The *safe load* which a beam can carry is found by dividing the breaking weight by a *factor of safety* suitable to the circumstances (see Volume I, Part II, page 260).

The actual dimensions of each of the different parts of a bridge should be so fixed, that *each portion* will be sufficiently strong to carry with safety the load to which it will be subjected

In calculating the dimensions of the scantlings of the timber used in bridges we shall have to take into account—

(*a*) the *dead* load—the weight of the bridge itself, which usually may be taken as being equally distributed over the whole of the supports.

(*b*) the *live* load, *i.e.*, the total weight of the maximum number of carts, pack animals, or men which *may* be on the bridge at one time.

In localities where strong winds or snow are prevalent allowances must be made for the horizontal force of the wind and the additional weight which the bridge will be required to carry, due to snow.

A bridge should, as a rule, be made strong enough to carry the greatest load which can be on it at one time, if this can be done without increasing the cost of the structure very considerably.

The live load may be distributed *evenly* over the whole length of the bridge, as, for example, a string of pack animals passing over it; or it may be applied to one point only, as in the case of a cart. In the latter case, the effect of the weight of the cart on the principal members of the bridge, will be greatest when the cart is *at the centre* of the bridge; and on the struts and ties when the cart is over the joints of the secondary members. In the calculations which follow, the beams investigated are rectangular in section and are supported near their ends.

§ 142. DETERMINATION OF THE DIMENSIONS OF THE PLANKING OF THE ROADWAY, AND THE LONGITUDINAL BEAMS OF A WOODEN BRIDGE.—The formula for calculating the breaking weight of a *rectangular beam,* supported at both ends, when *the weight is applied at the centre,* is given by the formula

$$W = \frac{P.\,b.\,d^2}{L} \quad . \quad . \quad . \quad . \quad (1),$$

while, if the weight is *equally distributed* over the whole length of the beam, the formula to be used is—

$$W = \frac{2\,P.\,b.\,d^2}{L} \quad . \quad . \quad . \quad (2),$$

where W = the breaking weight in lbs.
P = the co-efficient of transverse strength in lbs. (see table on pages 90 and 91, Volume I).
b = the breadth of the beam in *inches.*
d = the depth of beam in *inches.*
L = the length of the beam in *feet.*

From inspection of the above formulæ, we observe that the effect of the pressure of a *given weight,* applied at the centre of a beam, is equal to twice that of the *same weight,* if equally distributed over the whole length of the beam.

We shall also find on reference to Volume I, the table on page 259, that the factor of safety for a *live* load is double that allowed in the case of a similarly situated dead load, on account of the possible suddenness of its application. Also, if the live load is a concentrated one, as when a cart traverses the bridge, the straining action on the principal members of the bridge (the longitudinal beams, the trusses which support them) will be again doubled on account of the concentration. So that the stress which may arise from a concentrated *live* or travelling load, is four times that due to a uniformly distributed *dead* load of the same magnitude.

In order that the same formula may be used for calculating the size of a beam which has to carry either a dead load or a live load, or both a dead or a live load at the same time, it will be convenient to ascertain the amount of the *distributed dead load W*, which is equivalent to the combined distributed dead and concentrated live load, by adding the dead load to four times the amount of the live load and using the formula—

$$W = \frac{2\,P\,b.d^2}{L} \quad . \quad . \quad . \quad . \quad (3)$$

In this case the factor of safety for a *dead* load must be used.

The following factors of safety for wood are recommended in the report of a committee of the American Association of Railway Superintendents of bridges and buildings "on the strength of bridge and trestle timbers," dated the 16th October 1895:—

Factors of safety for wood.

In tension with and across the grain . . .	10
In compression with the grain	5
In compression across the grain	4
Shearing with and across the grain	4
Transverse rupture, extreme fibre stress . . .	6

Formulas (1) and (2), page 168, give the breaking weight of the beams, there considered. In calculating the dimensions of beams, we do not want to find out the dimensions of beams, which will break under the weight which will be applied to them; but the dimensions of the beams which will carry this load with safety, or the *safe load* which the beams can carry.

The *safe load* is necessarily less than the breaking weight or load, and is deduced from it by dividing the breaking weight or load by a factor of safety suitable to the circumstances.

Consequently, if w is the safe distributed dead load which can be carried by a beam supported at both ends and f the factor of safety,

$$w = \frac{2\,P.\,b.\,d^2}{f.\,L} \quad . \quad . \quad . \quad . \quad (4)$$

§ 143. Let us now take a simple example, to show the application of this formula to the calculation of the dimensions of the scantlings of a wooden bridge, constructed to carry a footpath across a ravine.

Assume that the span of the bridge (L) is 20 feet; that the roadway of the bridge is supported by two longitudinal beams, rectangular in section, resting on wall-plates, built into the abutments; that the horizontal distance between the longitudinal beams is 5 feet; that the planks of which the roadway is made are 8 feet long, and that they are laid at right angles to the longitudinal beams; and that the live load is a loaded sledge weighing, together with the men who take it down, 2,800 lbs. The wood used in the construction of the bridge is sâl (*Shorea robusta*).

Fig. 83.

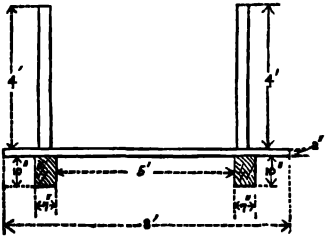

Figure 83 is a cross section of a simple wooden bridge, for purposes of calculating the dimensions of its constituent parts. a, a are the longitudinal beams, b the planking which constitutes the roadway, r, r the railing. (Scale = $\frac{1}{48}$.)

We now have to determine the thickness of the planking and the dimensions of the longitudinal beams.

Thickness of the planking.—The thickness of new planking is obviously made excessively strong, so as to provide a considerable margin for wear and tear, and the individual planks are retained, until they show liability to yield under the weight which they have to bear. The estimation of the *minimum* thickness of the planks is therefore somewhat unimportant.

Experience has shown that in the case of bridges on bridle paths, planks 2 inches thick are sufficiently strong to carry any load which may pass over them, and also to allow for considerable wear and tear.

In the case of bridges on cart-roads supported by three or more longitudinal beams, the planks should be made 3 inches thick where the traffic is heavy.

Dimensions of longitudinal beams.—In calculating the dimensions of the longitudinal beams, we have to take into consideration the joint effect of the *dead load* and the *live load.*

The dead load is uniformly distributed over the longitudinal beams and is supported equally by each. The dead load is made up of the weight of the longitudinal beams themselves, the weight of the roadway resting on them, and the weight of the railings.

The live load is also supported equally by the two longitudinal beams. The live load will produce the greatest straining effect when it is concentrated and placed at the centre of the bridge.

In the case under consideration the total load to be supported by each of the longitudinal beams will be—

Dead load—

	lbs.
The volume of one longitudinal beam (Sâl) 20 ft. × 1 ft. × 1 ft. = 20 c. ft., which at 75 lbs. per cubic foot is	1,500
The volume of the Sâl planking 2 inches thick; 4 ft. long × 2 inches × 20 (the length of the bridge in feet) = 13⅓ c. ft., which at 75 lbs. per cubic foot is	1,000
The weight of the railing, etc., say	340
TOTAL .	2,840

Note.—The dimensions of the longitudinal beams have been assumed for the time being, so as to allow of their weight being determined. The dimensions chosen should exceed what the actual dimensions are likely to be, so that the dead load may be too large rather than too small.

Live load—

	lbs.
One-half of the live load will be carried by each of the longitudinal beams, and in the case under consideration this is	1,400

The uniformly distributed dead load, which is equivalent to the above-noted dead and live loads (see page 169, § 142), will be

$$2,840 + 4 \times 1,400 = 8,440 \text{ lbs.}$$

The dimensions of the longitudinal beam should be such that this is the *safe* load w of the formula on page 170.

Using the formula given on page 170—

$$w = \frac{2 \text{ P } b . d^2}{f \text{L}}$$

and substituting the values, $w = 8,440$, $P = 800$ (see Volume I, page 91), $\text{L} = 20$, $f = 6$ (see table on page 169, factor of safety for transverse rupture), we get—

$$b\ d^2 = \frac{8,440 \times 6 \ \times 20}{2 \times 800} = 633,$$

b and d being in inches.

If we make the ratio of $b : d :: 1 : \sqrt{2}$ then we obtain the strongest beam possible (see page 151, fig. 64). Consequently substituting for d its value $b\sqrt{2}$ in the above equation we get—

$$2 \ b^3 = 633 \text{ cubic inches.}$$
$$\text{or } b^3 = 316{\cdot}5 \text{ cubic inches.}$$
$$\text{or } b = 6\ 815 \text{ (nearly) inches.}$$

Substituting this value in the equation—

$$d = b\sqrt{2}$$
$$\text{we get } d = 6{\cdot}815 \times 1{\cdot}414$$
$$\text{or } d = 9{\cdot}64 \text{ inches.}$$

The beams should consequently be 10 inches deep by 7 inches wide to allow for imperfections in the beams used.

It may often be convenient to use roughly squared beams instead of rectangular ones, and in this case $b = d$. Substituting this value in the equation—

$$b\ d^2 = 633$$
$$\text{we get } d^3 = 633$$
$$\text{or } d = 8{\cdot}59$$

that is to say, if we use square beams instead of rectangular ones, we must make the beams 8·59 inches square, or to allow for imperfections in the wood, say 8¾ inches square.

§ 144. DETERMINATION OF THE DIMENSIONS OF THE STRAINING BEAM AND STRUTS OF THE BRIDGE TRUSSES DESCRIBED IN § 131, PAGE 153

In the case of the simple strutted beam briefly described in §131, the following calculations give the stresses on the straining beam and struts. Let A B C D be a truss composed of a straining beam B C, and two struts A B and C D, resting on wall plates placed in the abutments A G, D H, while G H, the main longitudinal beam, rests partly on the straining beam and partly on the wall plates placed in the abutments.

In this form of trussed bridge, the length of the straining beam should be preferably ⅓ of the span, so that G B = B C = C H.

Then, considering the equilibrium of the bridge as a whole, it is clear that the weight is partly carried by the abutment and partly by the straining beam B C.

FIG 84.

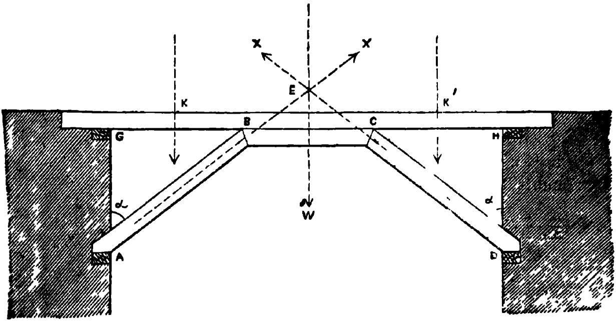

Figure 84 is a diagram of a strutted longitudinal beam described briefly in section 131 showing the forces acting on it. G H *is a longitudinal beam;* B C *the straining beam;* A B, C D *the struts supporting it.* K K' *the centres of the spans* G B, C H *respectively. The faces of the abutment* G A, H D *are in the figure vertical planes, a is the angle which the struts make with the vertical plane.*

So far as concerns the portions of the bridge G B and C H, half the weight of these portions will be carried by the abutments G H and half by the ends of the straining beam B C; because, since the centre of gravity of each of these portions of the bridge is equidistant from the points at which they are supported, the weight of each portion is carried equally by each support. Let K, K' be the centre points of the spans G B, C H respectively. Then the whole weight of the bridge from K to K', that is ⅔ of its length, is carried directly by the straining beam B C.

The straining beam is, in its turn, supported by the struts, AB, C D. Hence, if W be the weight of this central ⅔rds of the bridge, including the *live* load equivalent and the weight of the straining beam, the central portion of the bridge is kept in equilibrium by three forces, *viz.*:—The load W acting vertically downwards through the centre of the span and the compressive strains X, X on the struts, which are clearly equal from the symmetry of the figure. These must meet in E. Then if α be the angle made by the struts with the vertical wall of the abutment resolving vertically, we get—

$$
\begin{aligned}
W &= X\cos\alpha + X\cos\alpha. \\
&= 2X\cos\alpha. \\
\text{or } X &= \frac{W}{2\cos\alpha.} \\
&= \frac{W}{2}\sec\alpha \quad . \quad . \quad . \quad (5)
\end{aligned}
$$

It is also clear that the straining beam being supported by the thrust of the struts at either end of it, and a vertical force; it is under a compressive strain due to the horizontal components T of these thrusts; consequently—

$$T = X\sin\alpha.$$

Substituting the value of X found in equation (1), we get

$$
\begin{aligned}
T &= \frac{W}{2\cos\alpha} \times \text{Sin}\,\alpha \\
&= \frac{W}{2}\tan\alpha \quad . \quad . \quad . \quad . \quad (6)
\end{aligned}
$$

If there are three trusses of this kind in any bridge,—one at each side and one along the centre—the centre truss will carry ½ of the load supported by the three trusses and the outer trusses only ¼ each. The trusses would, in practice be made all the same size, and should be made strong enough to carry the largest stress to which any one of them is subjected.

From the nature of the load and its actual application, most of the stress will nearly always fall on the centre truss. This can, to some extent, be obviated, by not placing the outer trusses at the ends of the planks, but nearer the central truss. In the case of a bridge on a cart road, the side trusses should, if practicable; be placed where the wheels of the carts would come, or a little outside this.

W of the formulæ in equations (5) and (6) is equal to ⅔ of ½ of the weight of the whole superstructure and main beams of the bridge, and *live* load equivalent carried by the bridge, together with the weight of one straining beam.

And in any case, whatever the number of trusses, or the proportions the lengths B C, G B, C H may bear to one another, the weight W is easily determined by simple calculation.

If A is the sectional area of the *strut* in square inches, and A_1 that of the *straining beam* also in square inches, and r the greatest strain to which each square inch of the kind of wood used, can be subjected *with safety*, then,

$$\text{A should equal } \frac{X}{r} \text{ or since } X = \frac{W}{2 \cos \alpha}$$

$$= \frac{W}{2r} \sec \alpha \quad . \quad . \quad (7)$$

$$\text{and } A_1 \text{ should equal } \frac{T}{r} \text{ or since } T = \frac{W}{2} \tan \alpha$$

$$= \frac{W}{2r} \tan \alpha \quad . \quad . \quad (8)$$

care being taken that the *unit of weight* in W and r is the same, preferably pounds.

The value of r, used in the above formulæ, is deduced from *the resistance to crushing* of the wood (R) by dividing it by a factor of safety which should be taken as 5 or more (see table on page 169) to allow for the joints in the truss not being made to fit exactly. The numbers expressing the resistance to crushing

(R) of the principal Indian woods so far as they are known, are given in the table in Volume I, Part I, on pages 90 and 91, and are chiefly taken from the Roorkee Treatise on Engineering, Volume I, pages 177-188 of the 3rd edition (1878).

Struts and straining beams, and generally all such pieces which are compressed in the direction of their length, should be made square in section.

When the span of the bridge does not exceed 15 times the depth of the longitudinal beams, and when the struts are inclined at an angle with the vertical, not exceeding 45 degrees, it will be safe and convenient to make the struts and straining beam square in section, and of the same breadth as the longitudinal beams themselves. Greater dimensions for the struts will be required if the angle exceeds 45 degrees.

§ 145. DETERMINATION OF THE DIMENSIONS OF THE BRACE IN THE TRUSS DESCRIBED IN § 136, page 158.—If the length of a strut is more than eight times its depth, it should be fastened to the longitudinal beam by braces as described in § 136, page 161.

The object of this brace is merely to prevent the strut C D (fig. 84, page 173) "sagging" under the action of its own weight, which would render it less able to resist the compressive strain to which it is subjected. The brace is also of value in stiffening and strengthening the whole truss. The brace is most effective if attached to the middle point of the strut C D and at right angles to it. The brace, generally consists of two pieces nailed, one on either side of the principal members of the truss. The actual strain on the brace is due to part of the weight of the strut CD only, and is very small; but in consideration of the advantage of stiffening the whole structure, it is usually made to consist of two short stout planks of a combined sectional area of about ¼ that of the strut itself.

§ 146. CALCULATION OF THE DIMENSIONS OF THE STRUTS SUPPORTING THE KING-POST AND OF THE KING-POST ITSELF IN THE CASE OF A KING-POST BRIDGE TRUSS, SEE § 134, PAGE 157.

Calculation of the dimension of the struts supporting the King-post.—In a King-post truss the King-post itself is supported (see fig. 73, page 158) by the thrusts of the two struts which are framed into its upper end. The lower ends of these struts are butted into the ends of the tie beam. The central portion of the tie beam is suspended from the King-post itself. Secondary struts G and H are added to stiffen the long principal struts A L, A D, and prevent them from sagging under their own weight.

There are two such trusses one on each side of the bridge, and the weight of the roadway and traffic rests on the two beams which form the lower members of the trusses.

The dead weight will be borne equally by the two tie beams, and will be distributed uniformly along their length. The most severe straining actions due to the traffic may be taken to arise from a laden cart, which may not be in the centre of the roadway. To allow for divergence, it would be well to assume that the centre of the cart is as much away from the centre of the bridge as one-sixth of the width of the bridge. This would throw two-thirds of the weight of the cart on to one truss leaving one-third for the other. Since the divergence may be on either side, the trusses should be equally strong.

Suppose W_1 is the whole dead weight of the bridge, $\frac{1}{2}$ of $\frac{1}{2}$ of it (see fig. 85, page 178) will rest on the portion E B of the tie beam, and $\frac{W_1}{4}$ will rest on B F, uniformly distributed in each case. The King-post will be required to provide the support at B to the amount of $\frac{W_1}{8}$ for the weight which rests on E B, and another equal amount for the weight which rests on B F, the two together being $\frac{W_1}{4}$. This will subject the King-post to a tensile stress.

The weight of the traffic will have the greatest effect on the King-post and the struts when it is concentrated at B. Let W_2 = the whole weight of the traffic, supposed concentrated. Then as previously explained, $\frac{2}{3} W_2$ may be applied to one truss at B.

Consequently the whole load on the king-post will be $\frac{1}{4} W_1 + \frac{2}{3} W_2$, the first quantity being a *dead* load and the second a *live* load. The dead load applied at B which will be equivalent to these two, will in this case be the sum of the dead load and twice the live load or $\frac{W_1}{4} + \frac{4 W_2}{3} = T$ suppose.

Let us now consider the equilibrium of the head of the King-post. It is acted upon by three forces, *viz.*, the weight I which it supports, acting vertically downwards, and the two thrusts X, X of the struts (which it is clear from the symmetry of the figure must be equal) acting as shown by the arrows in figure 85 which is a diagram.

FIG. 85.

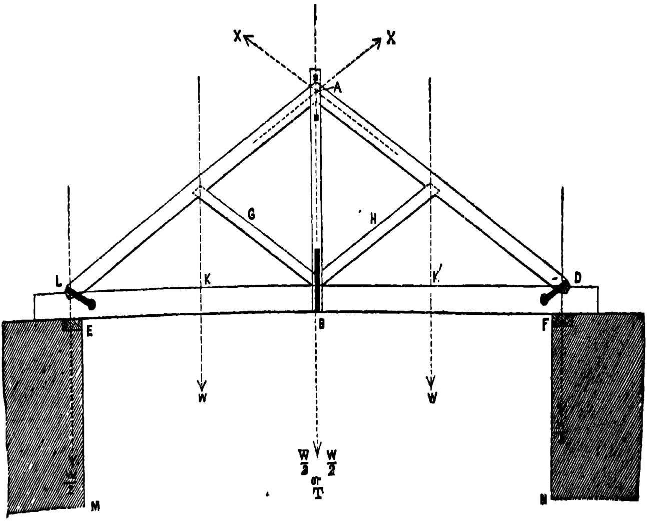

Figure 85 shows diagrammatically a King-post Bridge truss in elevation, and the lines of action of some of the forces to which its different parts are subjected. The line of action of these forces is shown by dotted lines, and their direction by means of arrows. A B *is the suspending piece.* A L, A D *the struts, which support it.* L D *the tie beam.* G *and* H, *struts added to strengthen the scantlings* A L, A D. B *is an iron stirrup which fastens the tie beam to the King-post.* K *and* K′ *the central points of the portions* E B, B F *of the tie beam.* E F, *the wall plates on which the tie beams rest.* E M, F N *the abutments of the bridge. Stirrups at* D *and* L *fasten the struts* A L *and* A D *to the tie beam* L D. *The struts* A D *and* A L *are also notched into the tie beam.* (*Scale* = [illegible].)

Then if α be the angle which the struts A D and A L make with the tie beam (which is horizontal), then, resolving vertically, we get

$$T = X\cos(90-\alpha) + X\cos(90-\alpha).$$
$$= 2X\sin\alpha$$
$$\text{or } X = \frac{T}{2}\operatorname{cosec}\alpha \quad . \quad . \quad . \quad . \quad (1)$$

and if A is the area of one of the principal struts (AL or AD) in square inches, then

$$A = \frac{X}{r} \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where r (see table on page 169) is $\frac{1}{8}$ of R, the resistance to crushing of the wood used, which is given in the table on pages 90 and 91, Volume I.

Calculation of the dimensions of a King-post or suspending piece.—The weight acting vertically downward through the King-post has been already determined and is T of the above formulæ; consequently, if A be the area of the King-post in square inches—

$$A = \frac{T}{r} \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

where r (see table on page 169) is $\frac{1}{10}$ of R, the resistance to crushing of the wood used. The values of R for the more common of the Indian woods are given in the table on pages 90 and 91, Volume I.

§ **147.** THE DIMENSIONS OF THE TIE BEAM.—The horizontal component H of the thrust X of the strut A D applied to the end of the tie beam D one way; and the horizontal component of the thrust X of the strut AL applied to the other end L of the tie beam LD, in the opposite direction, will cause the beam to be subjected to a tensile stress.

$$H = \frac{T}{2}\cot\alpha = \frac{T}{2} \times \frac{EB}{AB}$$

At the same time, the beam will be exposed to a stress, arising from the bending moment caused by the weight which rests on it. The beam has to be made strong enough to resist the combined tendency to fracture.

The greatest bending will occur when the travelling load W_2 is at quarter span, but at this time H will not be at its greatest value. When H is great, the bending is small. The exact estimation of the dimensions to safely withstand the combined stress is beyond the scope of this work.

It will be sufficient to calculate the dimensions of the beam for bending, supposing each half to be separately supported at its two ends, and loaded with a uniformly distributed dead load of $\frac{W_1}{4}$ and a concentrated live load of $\frac{2 W_2}{3}$, and in taking the strength P of the material of the wood (see table on pages 90 and 91, Volume I) to make a deduction of 10 per cent. as an allowance for the stress due to the tension H.

§ **148.** The secondary struts G and H, as previously mentioned, stiffen the principal ones A L and A D; the strain on them is not great, unless the principal struts are on the point of yielding laterally. In large spans the middle points of E B and B F are supported by iron tie rods, suspended from the joints where G and H are attached to the principal struts A L A D. In this case the thrust on G and H is a determinate amount, but not otherwise.

§ **149.** Iron rods circular in section are sometimes substituted for King-posts or suspending pieces. The diameter of the rod in inches is given by the following formula[1]

$$d = \sqrt{\frac{T}{7854}}$$

where *d* is the diameter of the rod in inches, T the pressure or weight acting in the direction of the rod in pounds, and 7854 the number of pounds which an iron rod one inch in diameter can support with safety.

SECTION V.—SIMPLE WIRE ROPE BRIDGES.

§ **150.** Simple wire rope suspension bridges may be used to carry a path across a wide swift stream with high banks, or over any other obstacle which does not admit of the use of intermediate supports. In forest works, bridges of this description are usually only required to carry either foot passengers or laden pack animals. The roadway of the bridge is suspended from two longitudinal wire ropes, firmly anchored at either side of the stream or other obstacle to be crossed. These ropes pass over the tops of posts or piers, placed on either side of the obstacle, and hang between them in the form of a parabolic curve.

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[1] Collection of designs for wooden bridges, by Lalla Kunhya Lall, 1860. Thomason College Press, Roorkee, page 91, § 252.

§ 151. RATIO BETWEEN THE TOTAL AMOUNT OF DEPRESSION OF THE ROPE AND THE SPAN —The amount of the tension on the longitudinal wire ropes of a suspension bridge depends upon, not only the weight of the bridge itself but also upon the relation of the depression of the rope at the centre of the bridge, below the head of the posts or pillars, on either side, over which it passes on its way to its anchorages,—to the span of the bridge (*i.e.*, the horizontal distance between the points on the posts or pillars on which the longitudinal wire rests). That is on the ratio of the length *c d* (fig. 86) to *a b*. The smaller this ratio is, the less will be the vertical component of the strain on the longitudinal ropes at their anchorages, and consequently the smaller will be the force which tends to drag the anchors themselves out of the ground. This is important, as unless the ends of the longitudinal rope are sufficiently strongly anchored, the bridge may fail owing to the ends of the rope being pulled out of the ground by the weight of the bridge.

FIG 86.

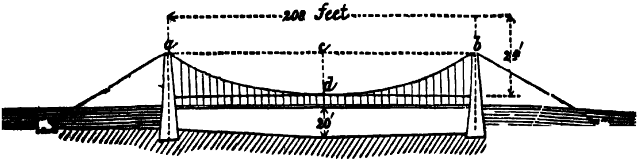

Figure 86 is an elevation of the Kullar suspension bridge, Coimbatore,[1] *c d should be 24 feet (scale 80 feet = 1 inch).*

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[1] Reduced from a drawing in *Indian Engineering*, edited by Pat. Doyle, Esq., C.E., for November 18th, 1893.

The smaller this ratio is, the greater will be the tension on the longitudinal ropes themselves, and also the greater the length of the ropes required.

Experience has shown that the ratio of the total amount of depression of the longitudinal ropes of a suspension bridge *c d* (fig. 86) to the span of the bridge, should be between 1 in 7 and 1 in 25. If the ratio exceeds the larger ratio (1 : 7) the force which tends to pull up the anchors of the bridge becomes too large , and if it is less than the smaller ratio 1 : 25 the tension to which the longitudinal ropes are subjected becomes too great. The most commonly adopted ratio between the total amount of depression at the centre of a suspension bridge and the span is about 1 : 14. In the case of the Tiuni suspension bridge, which takes the Mussoorie-Simla bridle path across the Tons river, a tributary of the Jumna, the length of the bridge from pier to pier is 190 feet, the total amount of depression at the centre of the bridge being 13 feet. This gives a ratio of 1 : 15.

The length of the Thadiâr suspension bridge, which crosses the same river about 8 miles higher up, is 146 feet, and the depression at the centre of the bridge 14 feet, giving a ratio of nearly 1 to 10½.

The length of each of the two spans of the Maindrot suspension bridge, which crosses the Tons between Thadiâr and Tiuni, is 85 feet, the depression in each case being 7 feet, which gives a ratio of 1 to 12.

§ 152. THE LONGITUDINAL WIRE ROPE.—The horizontal distance between the saddles on the piers, (see fig. 91, page 186) at one and the same end of a suspension bridge, (and consequently the distance between the ropes themselves), should be considerably greater than the width of the roadway of the bridge, (and consequently of the longitudinal ropes at the centre); and the distance between the longitudinal wire ropes at the anchorage should be, in like manner, proportionately greater. The greater the horizontal distance between the piers, at the same side of the bridge, and consequently between the longitudinal ropes at the anchorage, the wider will be the base of support of the ropes, and consequently the greater will be the force required to disturb the equilibrium of the system; since the larger the area of support (in this case the anchorage) is, the smaller will be the effect of a force (here the force which tends to pull the anchorage out of the ground and the lateral pressure of a strong wind) of given magnitude exerted on it per unit of area.

At Tiuni the distance between the wire ropes at the centre of the bridge is 4½ feet; and the distance between them, where they pass over the piers, is 11 feet 4 inches.

In the Thadiâr suspension bridge, the horizontal distance between the ropes at the centre of the bridge is 5 feet, and that between them where they pass over the piers 13½ feet.

The angles which the loop of the longitudinal rope between the piers make with vertical planes, at the points where it leaves the posts, are fixed when the ratio of the total amount of depression at the centre of the bridge to the horizontal distance between the posts (the span) is determined. These angles (A A, fig. 87) are the same on both sides of the bridge.

FIG. 87.

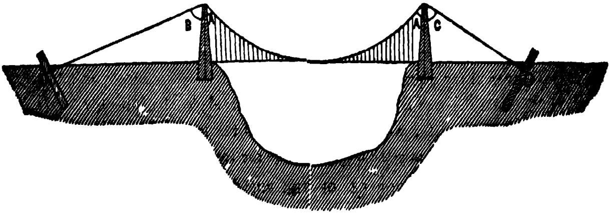

Figure 87 is a diagram to show the angles of depression (A A) of the part of ropes which supports the bridge, and of the angles of depression (B, C) of those portions of the rope, which pass over the piers and go to the anchors of the bridge.

But it is not necessary that the inclination to the vertical plane, of those portions of the rope which go from the top of the posts to the anchorages, should be equal to the inclination to the vertical plane of the loop of the rope. Nor is it necessary that the inclination of the portions of the ropes which pass from the top of the posts to the anchorages should be the same on either side of the bridge.

This statement is clearly shown in fig. 87, page 183, where the angles A, B, and C are all different.

The inclination of the ropes which pass to the anchorages on either side of the bridge, other conditions being equal, depends upon the nature and stability of the ground in which the respective anchorages of the bridge are to be made; and this is often of a perfectly different nature on either side of the obstacle to be crossed.

If possible, however, in order chiefly to simplify calculations, the inclination of the ropes which lead to the anchors on either side of the bridge should be the same. The larger the angle B or C is, (fig. 87, page 183), the smaller will be the vertical component of the force exerted on the anchors by the tension of the longitudinal rope, and the smaller will be the force which tends to drag the anchors out of the ground.

At Tiuni the angle A is 76° while the angles B and C are 72° and 68° respectively. At Thadiâr the angle A is 68¾°, while the angles B and C are nearly 57° and 72¾° respectively.

The size of the longitudinal rope depends upon the weight which it has to carry, the span, and the total amount of depression at the centre of the bridge.

If the span is constant, the larger the angle of depression is, the greater will be the tension on the longitudinal rope, and consequently the larger must be the rope.

§ 153. **ANCHORAGE OF THE ROPES.**—The stability of a suspension bridge depends to a very great extent upon the strength of the anchorage of the longitudinal wire ropes; and this, in its turn, depends in some degree upon the inclination given to those portions of the ropes, which lead from the tops of the piers to the anchors. The actual amount of the inclination given to the ropes, after they have left the piers, depends upon the nature of the ground in which the anchors of the bridge are placed. If a good natural anchorage cannot be obtained, the inclination of the rope to the horizon should be small, since the smaller this angle is, the smaller also will be the vertical force which will be exerted on the anchorage, and consequently the smaller the force which tends to drag the anchor out of the ground. The smaller this angle is, the greater the length of rope required, provided the height of the piers are fixed.

If a good durable hard rock is found *in situ*, it will be sufficient to bore holes in the rock, place iron stanchions in them, fill in the holes with molten lead or cement, and to fasten the longitudinal ropes securely to these stanchions. A mass of masonry should be built over the rock into which the stanchions are fixed, of sufficient weight to counteract the vertical component of the tension of the rope. The depth and diameter of the holes in which the stanchions are placed depend upon the weight of the bridge. Figure 88, page 186, shows how the longitudinal ropes are fastened at one side of the Tiuni bridge. The anchorage would be more stable if the direction of the stanchions was at right angles to that of the longitudinal ropes.

If the rock is not sufficiently hard to allow of the ropes being thus anchored, an artificial anchorage must be constructed.

The anchorage of the Thadiâr suspension bridge (fig. 89) is constructed of one deodar log, laid horizontally in the ground, and kept in position by three logs of either deodar (*Cedrus Deodara*) or shisham (*Dalbergia Sissoo*) placed in the ground and inclined at an angle of 57¾° with the horizon.

The ends of the longitudinal wire ropes from which the bridge is suspended are passed through the horizontal log, and then round it two or three times; after which the strands making up the rope are unwound, and fastened individually

FIG. 88.

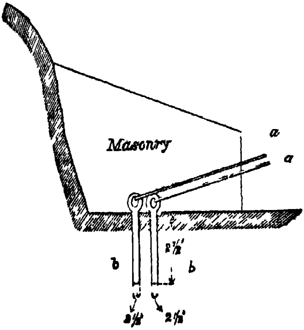

FIG. 89.

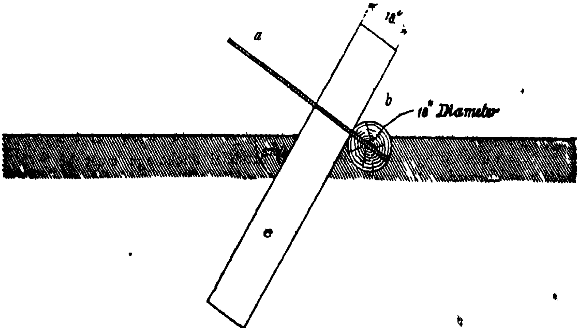

Figure 88 shows the anchorage of the Tiuni suspension bridge on the right bank of the river Tons. (From Professional Papers on Indian Engineering, No. CIII); a, a are the main longitudinal ropes; b, b the stanchions to which the ropes are fastened.

Figure 89 shows the anchorage of the Thadiar suspension bridge on the right bank of the River Tons. a is the longitudinal rope; b the horizontal log through which it is passed; c the inclined logs (there are 3 of them which keep the horizontal log in position. Scale = $\frac{1}{24}$.)

to the log. The diameters of the horizontal logs, as well as those of the inclined ones, are 18 inches.

The inclined logs are 7 feet long. The upper ends project about 18 inches above the level of the ground. A mass of dry rubble masonry is placed over one of the anchorages in order to protect it from being damaged by slips of the hill-side above. This mass of masonry does not rest upon the horizontal beam to which the longitudinal rope is fixed, and in consequence does not directly increase the strength of the anchorage. The horizontal logs were embedded in sand ; they were put down in 1876 and are still (1895) perfectly sound.

Figures 90 and 91 show an elevation and plan of the Thadiâr suspension bridge.

§ 154. PIERS.—In the case of light suspension bridges, such as a forest officer may have to construct in a hilly district, the main longitudinal wire ropes will usually pass over the tops of upright wooden posts, firmly embedded in the ground on either side of the obstacle to be spanned.

In large suspension bridges these wooden uprights are replaced by masonry piers, but the consideration of such structures is far beyond the scope of this book. These posts are necessary in order that the roadway may be kept well above the river-bed, and that sufficient waterway may be provided for the stream when in flood. For small bridges, the posts may be made of logs chosen from good, sound, mature trees of a durable species. The posts should be firmly embedded in the abutment of the bridge or in the ground. The heads of the posts should be tied together in order to prevent their separating.

These posts should be completely encased in wood so as to efficiently protect them from rain and weather.

The top of the post may have a notch cut in it to receive the main longitudinal wire rope, as shown in figures 92 and 93, page 188. Another method of forming the top of the post is, to substitute half of a flanged wheel or an iron saddle for the notch

FIG 92.

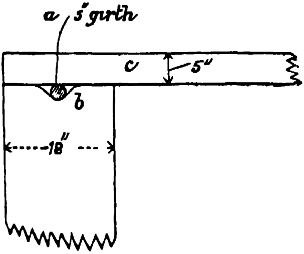

FIG. 93.

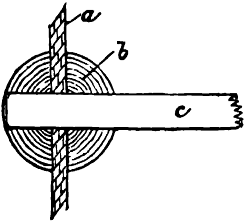

Figure 92 is the elevation and figure 93 the plan of the head of a pier of the Thadidr suspension bridge a is the main longitudinal rope, b is the notched head of the pier, c is the brace which ties the heads of the piers together (Scale = $\frac{1}{48}$)

cut in the top of the pier. In this case the main longitudinal rope (or ropes, if there are more than one) passes over the wheel or saddle. In the Tiuni bridge the ropes (there are 4 on each side) pass over an iron saddle fixed to the top of the posts. The ropes are kept in position by a metal stirrup which is bolted to the head of the post. (See figures 94, 95, page 189.)

The friction between the rope and the posts is considerably reduced by the introduction of the iron saddle, or flanged wheel.

The horizontal distance between the posts should, as has been previously stated, be considerably greater than that between the ropes at the centre of the bridge, in order that

FIG 94.

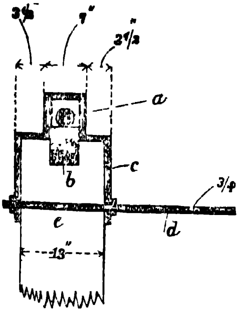

FIG. 95.

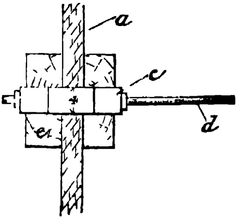

Figure 94 is a sectional elevation of the head of a pier of a suspension bridge. a is the main longitudinal rope in section; b is the iron saddle over which the rope passes; c is an iron stirrup which keeps the rope in position; d is an iron rod which ties the piers together; e is a part of the pier in elevation. Adopted from the Tiuni suspension bridge (Professional Papers on Indian Engineering, No. CIII). (Scale = $\frac{1}{24}$.)

Figure 95 is the plan of the same, the letters used are the same as in figure 94. (Scale = $\frac{1}{24}$.)

the stability of the structure; both as regards the direct force required to drag out the anchors of the bridge, and the lateral force due to the pressure of a high wind, may be increased.

The height of the posts depends upon the span of the bridge, the inclination of the longitudinal ropes, and the amount of waterway which must be provided. Their sectional area must be sufficient to support the weight of the bridge which rests on them.

§ 155. SUSPENDERS OR SUSPENSORS.—The small wire ropes, by which the roadway of the bridge is attached to the main longitudinal ropes, are called suspenders or suspensors. The size of these ropes depends upon the weight of the bridge and the live load which it has to carry.

The suspenders are fastened to the main longitudinal ropes at fixed equal *horizontal* distances. They may be fastened to the main rope in two ways—

(1) by being passed through it, and the strands of which the suspender is composed, opened out and twisted round the main longitudinal rope; the free ends of the wires being bound round by a single wire as shown in figure 96.

FIG. 96.

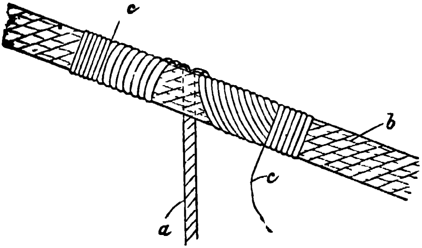

Figure 96 shows the method of fastening the suspenders to the main longitudinal rope adopted at the Thadiár Bridge. a is the suspender, b the main longitudinal rope, c the strand of wire wound round to strengthen the joint.

(2) if the suspenders cannot be passed through the main longitudinal rope, they may be first passed twice round the main rope, then twice round themselves; and the strands of which they are composed opened out and twisted round the suspender, with a single strand of wire as shown in figure 97. In order to prevent the suspender from slipping along the main rope, it is bound over by a single wire *c*, passed two or three times over the suspender and between the strands of the main longitudinal rope. This single wire forms a loop which prevents the suspender from slipping along the main longitudinal rope.

FIG. 97.

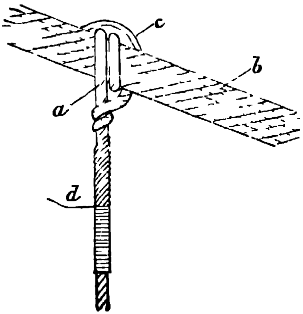

Figure 97 shows the method adopted at the Tiuni suspension bridge (Professional Papers on Indian Engineering, No. CIII). a is the suspender; b the main longitudinal rope; c the strands of wire used to prevent the suspender from sliding along the main rope; d the single strand of wire which completes the fastening of the suspender.

The arrangement for tightening wire when necessary, shown in figure 97*a*, page 192, may be introduced with advantage into the longer suspenders, so as to allow of their being adjusted to their proper length. The cross section of the iron rods of which the wire tightener is constructed, must be sufficient to bear the strain to which the suspenders will be subjected.

FIG. 97*a*.

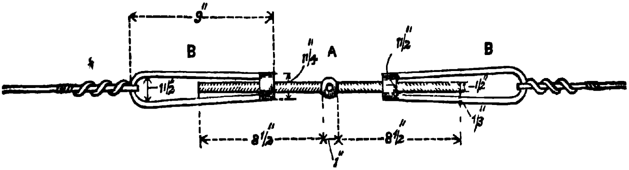

Figure 97a shows a contrivance for tightening iron wire A is a rod upon which the thread of a screw is cut, the thread is cut in opposite directions, on either side of the centre of the rod The rod A *works in two loops* B B, *to which the wire to be stretched is fastened The loops are brought nearer to each other by turning round the rod* A *by means of an iron bar placed in the hole in the centre of the rod (Scale* = ⅛)

The lower ends of the suspenders are fastened to the cross-pieces, upon which the longitudinal beams which carry the roadway rest. This may be done either—

(1) By passing the lower end of the suspender through a hole bored in the cross piece, opening out the individual strands of the wire of which the suspender is made, and driving a wooden plug into the hole from below, the individual strands being secured by small staples driven into the cross-pieces or

(2) By fixing a screw bolt ending in an eye, into the cross-piece, and fastening the lower end of the suspender to the eye of the bolt as shown in figure 98.

The suspender is passed through the eye of the bolt, opened out, wound round itself, and finally bound with a single strand of wire.

The second method is the better of the two, but if no eye bolts are available, then the first method must be resorted to.

The length of the individual suspenders should be such, that the roadway of the bridge when complete, should be almost horizontal; the centre of the bridge being, if anything, slightly higher than the ends. The roadway should be slightly *cambered* (*i.e.*,

FIG 98.

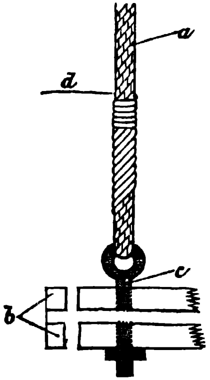

Figure 98 shows the method of fastening the lower end of the suspender to the cross pieces which carry the roadway on the Thadiar suspension bridge a is the suspender b the cross piece of which only a portion is shown, c is the eye bolt through which the suspender is passed d is the single strand of wire wound round the suspender to complete the joint (Scale = $\frac{1}{4}$)

its central portion raised slightly above the two ends) so as to ensure that after the suspenders have stretched, and the bridge has settled the roadway at the central portion of the span of the bridge, if not quite horizontal, shall be slightly higher than the ends A camber of 1 foot in a bridge 150 feet long will be sufficient The actual length of the individual suspenders may be determined graphically, in the first instance, by drawing to scale the curve made by the longitudinal wire rope, and then adding the roadway (with the required camber) as a tangent to this curve at its lowest point The suspenders placed at the fixed horizontal distances, should be added to this drawing and their exact lengths, as well as their relative positions on the longitudinal ropes, can then be scaled off When the horizontal distance between the ropes where they pass over the piers, is the same as that between the ropes at the centre of the bridge; the true length of the suspender will be seen in elevation, as the suspenders will in this case be truly vertical. But if, as is usually the case, the horizontal distance between the ropes where they leave the posts is greater than that between them at the centre of the bridge; the suspenders will not be vertical, but will be inclined at an angle to the vertical, which decreases as we go from the ends of the bridge to the centre; since the points at which the lower ends of the suspenders are fastened are all equidistant from the central line of the roadway of the bridge. Any individual suspender, will in this case, form the hypotenuse of a right angled triangle, the height of which is the *vertical* distance, from the point where the suspender is fastened to the longitudinal rope, to the top of the cross-piece to which the suspender is attached, produced; and the base is the *horizontal* distance, from the point where the suspender is fastened to the cross-piece, to this vertical line. Care should be taken, when determining the lengths of the suspenders, to allow a sufficient additional length of wire, for fastening the suspenders to the main longitudinal wire rope, and to the cross-pieces which carry the roadway. In large suspension bridges, the whole of the roadway, and the cross-pieces which support it, are suspended from the longitudinal rope. In small suspension bridges, such as are usually required in forest works, it is not necessary to follow this procedure. Two or three of the cross-pieces, in the exact centre of the bridge, often rest on the main longitudinal rope, and they should in this case be slightly notched, so as to allow of the main longitudinal ropes maintaining the correct curve which has been assigned to them. The longitudinal rope then passes over 2 or 4 more of cross-pieces, which are notched (if necessary) to maintain the true parabolic curve; these are bound directly to the longitudinal rope. The remaining suspenders are fastened as described on page 192, and their individual length increases as they depart farther and farther away from the centre of the bridge.

If the wire strainer figured on page 192 be introduced into the longer suspenders, the length of the latter can be very accurately adjusted in the first instance; and can be slightly altered from time to time, if it is found that the suspenders have stretched unequally, either owing to the weight they have to carry, or to changes of temperature. If we keep the length of the suspenders adjusted correctly, we can ensure that each suspender does carry its proper share of the weight of the bridge. The suspenders in this case may be made, if anything, slightly too long at first and shortened by means of the wire strainers to the required length, after the cross-pieces have been placed in position, and the suspenders have stretched, as much as they will do, owing to the weight to which they are subjected.

§ 156. THE ROADWAY.—The longitudinal beams of the bridge rest on the cross-pieces, which in their turn are suspended from the main longitudinal ropes. The planks which form the roadway are fastened directly to the longitudinal beams. Figure 99 is a cross section of the Thadiâr suspension bridge to show the construction of the roadway.

In the Thadiâr bridge, the posts carrying the wire, which constitutes the railing of the bridge, pass through the planking and are tenoned into the cross-pieces; while small wooden struts are added at the level of the roadway in order to strengthen them.

It would have been better to have made the cross-pieces longer and to have added struts in one of the methods described in § 139, page 164 *et seq.*

The struts can easily be arranged so as not to interfere with the attachment of the suspenders to the cross-pieces.

The planking which forms the roadway may be laid at right angles to the direction of the length of the bridge or else diagonally as has been described on page 162, § 138, in connection with the roadway of simple wooden bridges. It is a good plan to place a second layer of thin planks along the central portion of the roadway where the bulk of the traffic

FIG. 99.

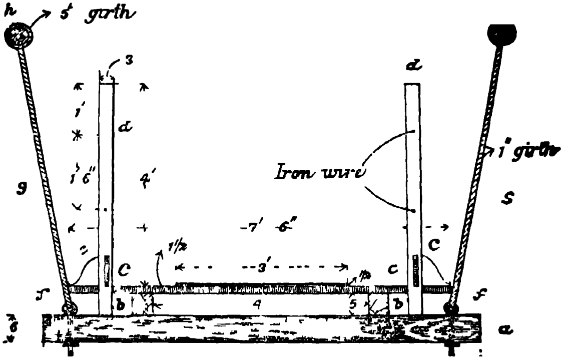

Figure 99 is a cross section of the Thadiâr suspension bridge. a is a cross piece in elevation, b, b the longitudinal beams in section, c, c the planks which form the roadway; d, d the railing; e, e the struts which strengthen the uprights of the railing; f, f the eye bolts to which the suspenders g, g are fastened; h, h the main longitudinal ropes in section. (Scale=$\frac{1}{32}$)

falls. These can be renewed when necessary without taking up the whole of the roadway.

§ 157. Suspension bridges are more liable to damage from sudden storms of wind, than are the more common forms of bridges. A strong wind blowing up or down the valley, in which there is a suspension bridge can cause the bridge, specially if it is a light one, to sway considerably, and in so doing it may seriously strain the structure.

Where there is a danger from high winds, the rigidity of the structure can be materially increased, by the addition of small wire ropes (guy lines), which should be fastened to the longitudinal beams of the bridge, and to the shore, both above and below the bridge. The wind will not be able to cause the bridge to sway much until the guy ropes are either broken or the anchors to which they are fastened are pulled out bodily. Suspension bridges are also peculiarly liable to be strained by the oscillations set up by a large body of men keeping step marching over them. The oscillations increase rapidly in degree; and soon become sufficiently serious to endanger the stability of the whole structure. For this reason men should never be allowed to keep step when crossing a suspension bridge.

§ 158. CALCULATIONS NECESSARY FOR THE DETERMINATION OF THE DIMENSIONS OF THE DIFFERENT PARTS OF A SUSPENSION BRIDGE AND THE CONSIDERATION OF THE CONDITIONS NECESSARY FOR THE MAINTENANCE OF ITS EQUILIBRIUM.* The only suspension bridges, that it is necessary to consider in connection with Forest Engineering, are such as are required to carry a footpath or mule-track across a river, that cannot conveniently be bridged in any other way: large and expensive road bridges are not within the scope of this work.

Such bridges are generally constructed of iron or steel wire ropes carrying a wooden roadway, the end piers consisting of stout wooden frames on a masonry foundation.

Broadly speaking, a suspension bridge consists of a lightly constructed roadway, hung by suspending ropes from two parallel main ropes that run the whole length of the bridge.

These main ropes hang in a loop between the tops of piers considerably elevated above the roadway at either end, and are anchored in the ground beyond.

This loop can have any convenient form which may be dictated by the conditions of the site; and the effect of different forms of loop on the strains acting on various portions of the structure; in view of the nature and strength of the materials available. For a given span and kind of roadway, the greater the dip given to the ropes, the less will be the strain on them; but against this advantage must be set the extra height of the piers and length of rope required.

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* Communicated by C. E. Dupuis, Esq., F.C.H., Executive Engineer, P. W. D., Irrigation Branch.

Common proportions between the span and the dip of the rope vary from 10 to 20 to 1

In designing a suspension bridge of this kind, it is therefore necessary first to determine the nature of roadway required, the span of the bridge, and the dip of the main rope—these fundamental points having been settled, the necessary dimensions of the various parts of the structure are determined in detail as follows

§ 159. FORMULÆ FOR CALCULATING THE DIMENSIONS OF THE MAIN ROPES OF A SUSPENSION BRIDGE.

The ropes support—

(1) Their own weight.
(2) The weight of the suspenders.
(3) The weight of the roadway.
(4) The live load.

Let this total weight $= W$

This weight may be considered for all practical purposes to be equally distributed throughout the length of the bridge in reality, it is slightly greater at the ends.

Consider the case of *one* of the main ropes

This rope supports an evenly distributed load of half the total weight of the bridge and its load, and is in strong tension throughout

In Fig 100, if A be the lowest point on the rope (*i e.*, the centre of the span), B the point on the rope where it passes over a pier, A E C the roadway, and B C a pier, half of the total load on the rope, that is, one quarter of the *whole weight of the bridge* or $\frac{W}{4}$ is supported by the length of rope A B.

Since the weight is uniformly distributed, the line of action of the resultant force due to this load will bisect A C at E.

The portion of rope A B is then maintained in equilibrium by three forces, namely —

(1) A vertical force, equal to one quarter of the total weight of the bridge and its load acting through E. $\Big\} \; \frac{W}{4}$

(2) The tension of the rope at its lowest point, a horizontal force acting along the line C A and therefore passing through E. $\Big\} = H$

(3) The tension of the rope where it leaves the top of the pier acting along the tangent to the rope at that point the line of action of this force must therefore also pass through E $\Bigg\} = T$

Then E K B is a triangle of forces, and since the forces are proportional to the sides along which they act, we have

$$\frac{W}{EK} = \frac{T}{EB} = \frac{H}{KB} \quad . \quad . \quad . \quad . \quad (1)$$

Let x be the span of the bridge, y the depression of the lowest point on the rope below the top of the pier (*i.e* the dip of the rope), α the angle of depression of the rope where it leaves the pier

$$\text{Then } EK = y \qquad KB = \frac{x}{4}$$

$$\text{and } EB = KB \sec\alpha = \frac{x}{4} \sec\alpha$$

FIG 100.

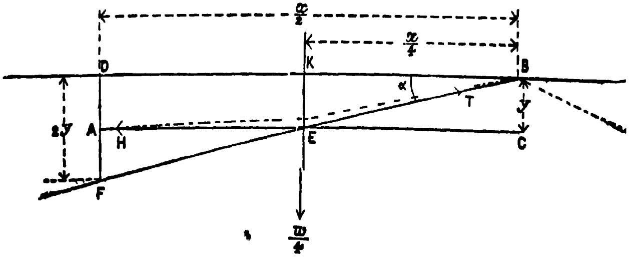


Figure 100 is a diagram to show the conditions of equilibrium in the case of a suspension bridge. A B G *is the longitudinal wire rope* A *is the central point of the span and the lowest point of the rope.* G *is the anchor of one of the main longitudinal ropes* D B *is a horizontal line through the top of the pier* B C D B *is half the span of the suspension bridge.* B F *is the tangent to the curve made by the longitudinal rope where it leaves the head of the pier The angle* D B F = α C A *is parallel to* B D E *is the centre point of* A C *and* K *is the centre point of* B D

The directions in which the forces along K E, F, B, *and* C A *act are shown by arrows*

Substituting these values in equation (1)

$$\frac{W}{4y} \quad \frac{4T}{x \sec \alpha} = \frac{4H}{x} \quad . \quad . \quad . \quad . \quad (2)$$

$$\text{Hence } H = W \frac{x}{16y} \quad . \quad . \quad . \quad . \quad . \quad (3)$$

and

$$T = W \frac{x \sec \alpha}{16y} \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

Expressing equation (3) in words, we learn that the tension of one of the main ropes of a suspension bridge, at the centre of the span, is equal to the total weight of the bridge and its load, multiplied by the span, and divided by sixteen times the dip of the rope.

Equation (4) tells us that the tension of the rope where it leaves the pier, is equal to the tension at the centre of the span, multiplied by the secant of the angle of depression of the rope where it leaves the pier.

This angle α is the angle whose tangent is $\frac{2y}{\frac{x}{2}}$ or $\frac{4y}{x}$, and is therefore definitely fixed as soon as the proportion between the span and the dip of the rope has been settled.

The secant of an angle is always greater than unity, but approaches to it as the angle becomes small; hence since from equation (2)

$$T = H \sec \alpha,$$

it is known that the tension of the rope where it leaves the pier must always be greater than the tension at the centre of the span, but approaches to it as the angle α diminishes, that is, as the dip given to the main rope decreases.

In the extreme case of a very tight rope, y is very small relatively to x, and the angle α is very small, so that T and H are nearly equal, and may be indefinitely great.

In the opposite extreme case of a very slack rope, the tension H at the centre of the span becomes indefinitely small, while T is also small, and tends to approach $\frac{W}{4}$ (but in this case the assumption made at the commencement of these calculations, that the load is uniformly distributed over the bridge, becomes rather seriously incorrect).

In practice the angle α is generally small, and sec α not much greater than unity, so that H and T are nearly equal, that is, the tension on the main ropes of a suspension bridge is, in ordinary cases, nearly the same throughout.

In designing a suspension bridge, the strength of the ropes should of course be calculated for the greater tension T, thus giving a slight excess of strength in the central portions of the span.

This tension T has been shown to be

$$W \frac{x \sec A}{16\, y} \quad , \quad . \quad . \quad . \qquad (4)$$

x and y have been supposed to be already determined from fundamental considerations.

x *the span*, depending on the conditions of the site, such as the highest flood level, waterway required, suitable positions for piers, etc.

y *the dip of the rope*, being fixed more or less arbitrarily, but with consideration of the effect of the relative proportions of x and y on the strains noted above, facilities for anchorage, and architectural effect.

Then being expressed in terms of the *same unit* (preferably feet)

α is the angle whose tangent is $\frac{4y}{x}$

Note,—A table of the natural trigonometrical functions of angles is given in Appendix I, page 255.

W, the *whole* weight of the bridge *plus the live load*, depends on the nature of the roadway required, and the traffic to be provided for. To determine the value of W, the weight of the various parts of the bridge should be worked out separately, and added together; these parts consist of

(1) *The two main longitudinal ropes* between the tops of the piers.

(2) *The suspenders*, of which there may be any convenient number.

(3) *The cross pieces, longitudinal beams and planking* of the roadway itself.

(4) *The railings* on either side together with all hooks, bolts, washers, nails *and other ironwork.*

(5) *The live load,* which is generally expressed as so many pounds per square foot of road surface.

Of these, the weights of (3), (4) and (5) are known at once by simple calculation, those of (1) and (2) require to be determined, in the first instance, tentatively with the aid of the following table, in a manner that is most clearly indicated by an example, see § 166, page 212.

The tension T is thus fully known and can be expressed in pounds or any other convenient unit, and the required size of wire for the main ropes determined.

The following table, adapted from Molesworth's Pocket Book of Engineering Formulæ, gives the *working strength* and weight of iron and steel wire ropes of different sizes —

Circumference of rope in inches	IRON WIRE.		STEEL WIRE.	
	Weight per foot run in pounds	Working strength in pounds	Weight per foot run in pounds	Working strength in pounds
1	14	650	15	1,008
1¼	23	1,008	·23	1,568
1½	33	1,456	33	2,262
1¾	44	1 994	·45	3.091
2	·58	2,598	·59	4,032
2¼	·73	3,293	75	5,107
2½	·91	4,056	·93	6,294
2¾	1 10	4 906	1 12	7,616
3	1 30	5,846	1·33	9,072
3¼	1 53	6,854	1 57	10,640
3½	1 78	7,952	1 82	12,342
3¾	2 04	9,139	2 09	14,179
4	2 32	10 394	2·37	16,128
4¼	2 62	11,738	2 68	18,211
4½	2 94	13,149	3 00	20,406
4¾	3·27	14 650	3 34	22,736
5	3 62	16,240	3 70	25,200

The *factor of safety* for iron and steel wire in the above table has been taken as 6:—*i.e.*, the *breaking strain* of the ropes is 6 times the working strengths given.

§ 160. CALCULATIONS FOR THE DIMENSIONS OF THE SUSPENDERS.

There may be any convenient number of suspenders, arranged in pairs, one on each side of the bridge. They are placed at equal horizontal intervals along the bridge (the interval from the pier to the first suspender at either end being also the same).

Let the number of suspenders on each side be n, then the bridge is divided up into $n+1$ segments, n of which are carried by a pair of suspenders each (the remaining segment being made up of two half segments supported by the piers at either end).

The weight supported by the suspenders is the weight of n of these segments of the bridge less the weight of the longitudinal wire ropes: if this is W′, then the weight of each segment of the bridge carried by a pair of suspenders is

$$\frac{W'}{n+1} \quad . \quad . \quad . \quad (5)$$

and the strain on each suspender

$$T_1 = \frac{W'}{2\,(n+1)} \quad . \quad . \quad (6)$$

From this, the necessary dimensions can be found from the table on page 202, giving the working strength of wire ropes of different sizes. The strain on each suspender must not exceed the working strength of the rope of which it is constructed.

§ 161. STRAINS ON THE ANCHORAGE OF THE MAIN ROPES.—Since the main longitudinal wire ropes are continuous, and only pass over the tops of the piers as over pullies, the tension of each rope from the last suspender to the anchorage is practically the same throughout; the only other external force acting on this part of the rope being its own weight which is relatively inconsiderable, if the distance from the pier to the anchorage is small; under these conditions, the portions of the ropes from the piers to the anchorages are approximately straight lines; and the strain on the anchorage due to each main rope is that due to the tension T of the rope, acting along the line on which the ropes leave the anchorage.

FIG. 101.

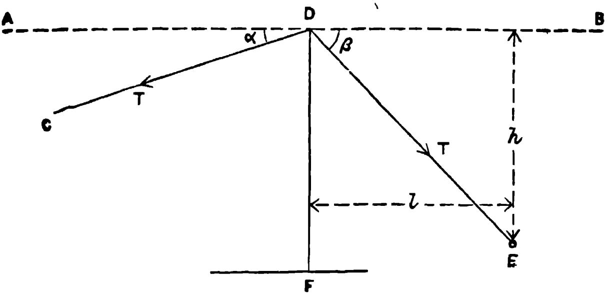


Figure 101 is a diagram to show the strains which are generated at the anchorage of a suspension bridge. C D E is part of one of the main longitudinal ropes anchored at E, and passing over the top of the pier at D. D F is the pier, over the head of which the main longitudinal rope passes T shows the tension exerted on the rope near the head of the pier and along that portion of the rope which leads to the anchor. α is the angle of depression of that portion of the main longitudinal which carries the bridge, and β the angle of depression of the portion which leads to the anchor h is the vertical distance of the anchorage at E below a horizontal line passing through the head of the pier, while l is the horizontal distance of the anchorage from the pier D F.

In figure 101, C D E is a main rope anchored at E and passing over the top of a pier at D, then the distance D E being small, D E may be regarded as a straight line, and if β be the angle of depression of the rope D E, the anchorage at E is acted on by a force T, whose horizontal and vertical components are respectively

$$\text{Horizontal} = T \cos \beta \quad . \quad . \quad (7)$$

$$\text{Vertical} = T \sin \beta \quad . \quad . \quad . \quad (8)$$

In practice, the angle β is determined by the conditions of the site, and if l be the distance from the pier to the anchorage horizontally, and h the difference in height of the anchorage E and the top of the pier D.

β is the angle whose tangent is

where h is the vertical distance of the anchorage below the top of the pier, and l is the horizontal distance of the anchorage from the pier itself; from which, the value of the above forces can be calculated; and though not absolutely correct, they are quite near enough for all practical purposes in ordinary cases

If, however, a suitable site for the anchorage is not obtainable near the pier, so that the length D E becomes considerable, the rope assumes a curved form under the influence of its own weight acting on it uniformly throughout. Though this weight will seldom be sufficient to materially affect the strain on the rope, yet the curve assumed by the rope alters the direction of its action, the tendency being to increase the horizontal and decrease the vertical component, until, in an extreme case, the rope leaves the anchorage horizontally, when the vertical component becomes zero, and the horizontal component the whole tension of the rope.

In such a case, a natural modification of the design is to utilize the portions of the main ropes between the piers and the anchorage to carry an extension of the bridge roadway. The simplest case is that in which the bridge consists of one whole and two half spans From the symmetry of such a figure it is clear that in this case the main ropes will leave the anchorage horizontally with a tension H, equal to that at the centre of the main span; and as H is always less than T, it is worthy of note that the addition of the extra length of bridge roadway in no way adds to, but on the contrary *diminishes*, the strain on these portions of the main ropes, and is consequently often an economical arrangement.

§ **162.** The anchorage of the ends of the main ropes may be effected in various ways.

If solid rock be available in a suitable position, the ends of the ropes may be attached to iron stanchions let into and fixed into it by "leading." (See page 184, § 153.)

Such iron stanchions will generally be fixed as nearly as possible at right angles to the line in which the ropes leave the anchorage, and the ropes will be attached to the stanchions as close to the rock as possible.

The principal strain to which such a stanchion will be subjected will then be a shearing force T where the stanchion leaves the rock.

The dimensions of the stanchion must be calculated to resist this strain.

The shearing strain on a wrought-iron stanchion should not exceed 10,000 lbs. per square inch of section.

Another method of anchoring the ropes, is to fasten the ends of the longitudinal ropes tightly round a stout log laid horizontally, and at right angles to the line on which the rope leaves the anchorage. This horizontal log is kept in position, by two or more inclined logs (in vertical planes) placed as shown in fig. 89, page 186. These in their turn are backed up with, or built into sufficient earthwork or masonry, to prevent any possibility of their moving forward under the strain. The scantling of the wood employed scarcely needs elaborate calculation, but should, of course, be roughly estimated with a liberal margin for safety. Logs of any strong and durable wood 1 foot in diameter will generally be ample. The shearing strain of English oak is 2·03 tons per square inch (Molesworth) and such a wood as Sissoo (*Dalbergia Sissoo*) is at least as strong as English oak.

§ 163. The piers at the ends of a suspension bridge of the kind under consideration, will generally consist of a framework of wooden beams, made up of two vertical posts or standards, joined together above and below by cross-pieces or transoms; the roadway passing through the frame.

The main ropes pass over the heads of the standards resting in cast-iron saddles, and it is a good thing to protect the whole head of the frame by a light wooden roof. The transoms are merely to strut the ends of the posts apart and keep them in position, laterally. An iron tie rod in addition to the wooden transoms is an additional safeguard against any tendency of the tops of the posts to spread. These connections necessarily tend to add strength and rigidity to the whole structure; but the dimensions of the standards should be calculated in each case, to resist the strains thrown on them by the ropes passing over their heads.

The lower ends of the standards should be sunk into the ground, or built into masonry, so as to act as vertical cantilevers, supported at their lower ends, in resisting any tendency of the strains produced to thrust over or break them; and their dimensions should be calculated accordingly.

If, however, this is for any reason impossible, and the piers consist merely of wooden frames resting on a rock or masonry foundation; then the tendency of the pier to fall over, in the direction of the resultant force acting on its head, must be resisted by ties or struts, or by actually attaching the main ropes to the heads of the piers where they pass over the saddles. But it must be remembered that the latter proceeding to some extent, falsifies the preceding calculation, as the ropes will no longer pass over the saddles as over pullies.

In any case, it is always desirable so to design the bridge, as to reduce the horizontal component of the resultant force acting on the head of a pier to a minimum; and to let the pier be subject to a simple compressive vertical strain only, if possible. This will be attained by making the angles of depression of the rope on either side of the pier as nearly as possible equal.

Considering the more usual case of piers acting as cantilevers, the following calculations show how to determine their required dimensions.

§ 164. CALCULATIONS TO DETERMINE THE DIMENSIONS OF THE PIER STANDARDS.—The forces which cause the strains on a standard are the two equal forces T, T acting at the top of the pier along the lines on which the main rope leaves it; and its own weight, which is relatively inconsiderable, and may be neglected.

FIG 102.

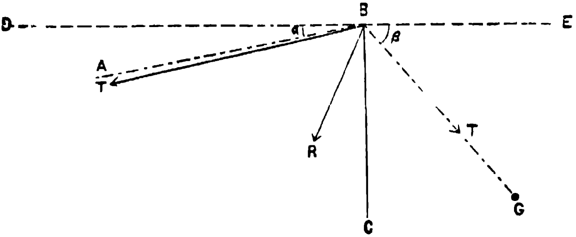


Figure 102 is a diagram to show the strains exerted at the head of a pier of a suspension bridge.

The tension on the two portions of the longitudinal rope A B G *is* T *Arrows indicate the direction in which these forces act. The full line below the broken line, which represents the longitudinal rope shows the direction of the tension on the rope where it leaves the head of the pier.* G *is the anchorage of the longitudinal rope.* B C *is the post over the head of which the rope passes.* D B E *is a horizontal line through the head of the pier.* α *is the angle of depression of that portion of the rope which supports the roadway, where it leaves the top of the pier, and the angle of depression of that part of the rope which goes to the anchorage of the bridge.*

In figure 102 B C is a standard (see § 163, pages 206, 207) A B G the line of the main rope passing over it, G the anchorage, D B E a horizontal line through B.

D B A$=\alpha$ and E B G$=\beta$ the angles of depression of the rope as it leaves the pier, in the direction of the bridge and anchorage respectively.

Then the pier B C is under the action of two forces each equal to T acting along the lines B A and B G.

Resolving these two forces into their vertical and horizontal components, we have the following forces acting at B

a vertical force $v = \mathrm{T} \sin \alpha + \mathrm{T} \sin \beta$.

a horizontal force $h = \mathrm{T} \cos \alpha - \mathrm{T} \cos \beta$.

If the angles of depression α and β be equal, h vanishes, that is, there is no horizontal force acting on the pier, the pulls in either direction exactly balancing one another, and the vertical force $v = 2\ \mathrm{T} \sin \alpha$.

But

$$\mathrm{T} = \mathrm{W} \frac{x}{16\,y} \sec \alpha \quad . \quad . \quad (4) \S\ 159, \text{ page } 198.$$

$$\therefore \quad v = 2\ \mathrm{W} \frac{x}{16\,y} \tan \alpha$$

$$= 2\ \mathrm{W} \frac{x}{16\,y} \times \frac{4\,y}{x} = \frac{\mathrm{W}}{2} \quad . \quad . \quad (9)$$

or each standard supports a direct vertical pressure equal to half the total weight of the bridge.

This is, as stated at the end of the last article, a favourable state of things, and convenient from its simplicity; it is not, however, always possible so to arrange the anchorage that the angles of depression of the main rope on either side of the pier shall be the same.

If the angles α and β be not equal, then the resultant force acting at B

$$\mathrm{R} = \sqrt{v^2 + h^2}$$

$$= \mathrm{T}\sqrt{2 \left\{ 1 - \cos\,(\alpha + \beta) \right\}}$$

and acts along a line making an angle equal to half the difference of the angles of depression, that is $\frac{\beta - \alpha}{2}$ with the vertical.

It is, however, nearly always best to treat the components of such forces separately.

Taking first the vertical component of the force acting on the pier, it is clear that this is a pressure producing a uniform compressive strain throughout the pier, the intensity p_v of which depends on its section.

The horizontal component gives a bending moment tending to thrust over or break the pier, which is a cantilever supported at one end; and the magnitude of this bending moment and the strains it produces, depend on the magnitude of the horizontal component, and the height and section of the pier; the greatest strains are produced at the bottom of the pier, and are tensile on one side of the pier, and compressive on the other, and of equal intensity.

The pier being already subject to a considerable compressive strain, due to the vertical component, it is clear that the greatest strain produced by the combined action of the two components will be compressive.

Let the maximum compressive strain produced by the horizontal component be p_h.

Then the section of the standard must be such, that if p_m be the limiting intensity of strain permissible in the wood of which it is composed

$$p_h + p_v \text{ must not exceed } p_m.$$

Let the section of the standard be l inches x b inches, being measured in the direction of the length of the bridge, that is, in the direction of the line of action of the horizontal component, and y inches its height.

$$\text{Then } p_v = \frac{v}{b\,l} \quad . \quad . \quad (10)$$

and by the principles of applied mechanics

$$p_h = M\frac{x}{I} \quad . \quad . \quad (11)$$

where M is the moment of the horizontal component force h about the base of the pier.

x is half the diameter of the pier in the direction of action of v, that is, $x = \frac{l}{2}$

and I is the moment of inertia of the section of the beam

and here is $= \frac{l^3 b}{\ }$ therefore $p_h = \dfrac{vy\,\dfrac{l}{2}}{\dfrac{l^3 b}{12}} = \dfrac{6\,vy}{b\,l^2}$ . . (12)

at that edge of the standard towards which the horizontal component acts.

Expressing the forces v and h in pounds, and the dimensions b, l, and y, in inches, p_v and p_h are in lbs. per square inch.

And $p_h + p_v = p_s$ the maximum intensity of strain, in lbs. per square inch, to which the wood of the standard is subjected in any part, and the dimensions v and h must be so selected that p_s may not exceed p_m;

This can be done tentatively in two or three trials. Generally speaking, l should be to b in about the proportion of 3 to 2, but when the horizontal component is very small relatively to the vertical, a square or nearly square section is better.

The dimensions of the transoms and tie bolts do not need elaborate calculation. In fact, theoretically, they are not subject to any strain at all under the conditions that have been assumed throughout these calculations, namely, that the main ropes are parallel. This, however, is not, as a rule, quite the case, as they are generally rather further apart at the ends of the bridge than at the centre.

This deviation from parallelism is not sufficient to affect the correctness of the foregoing calculations appreciably, but may produce some lateral strain on the heads of the standards which is resisted by the transoms and tie bolts.

The lower transom of the pier frame is often prolonged some distance beyond the standards on either side, and the whole framework further stiffened and strengthened by the addition of outside struts from the ends of the lower transom to the standards near their heads.

§ 165. CONSTRUCTION OF ROADWAY.—For an ordinary suspension bridge of this kind carrying a 4-foot roadway, the suspenders may be about 5 feet apart horizontally (see fig. 90, page 186*a*).

The suspenders are attached to the cross-pieces by suspending hooks bolted through them.

On the cross-pieces, and bolted to them, are laid a double line of stringers (longitudinal beams) at a distance apart, about 2 feet less than the width of the roadway, to carry the ends of the road planks, which are laid across and nailed to them.

A light but strong and suitable railing must be added on each side to protect the traffic.

The ends of the cross-pieces project about 2 feet beyond the sides of the roadway; and short struts, from these to the uprights of the railing, support and strengthen them.

§ 166. EXAMPLE OF THE METHOD OF CALCULATING THE DIMENSIONS OF THE VARIOUS PARTS OF A SUSPENSION BRIDGE.—A river is to be bridged on a hill road. It is decided from an inspection of the site, that the bridge had better be a suspension bridge—convenient sites for the end piers exist 180 feet apart; 15 feet is fixed on as a suitable amount of dip for the main ropes; solid rock exists on either bank, and it is decided to anchor the ropes to stanchions, leaded into the rock at points 20 feet behind the piers horizontally and 5 feet above the road level.

The bridge roadway is to be 4 feet wide, made up of $1\frac{1}{2}$ inch deodar planks, supported by 4 inches × 4 inches stringers laid on 5 inches × 4 inches cross-pieces, 5 feet apart; the cross pieces being suspended at their ends by light wire ropes from the main ropes (also of iron wire) and carrying a light wooden railing.

There being no difficulty in so arranging it, the level of the road is so adjusted that it just touches the loop of the main ropes at their lowest point.

From the equation $\tan \alpha = \frac{4\,y}{x}$ (§ 159, page 198).

$$\tan \alpha = \tfrac{60}{180} = \tfrac{1}{3} = \cdot3333$$

From the table of natural functions in the Appendix I, pages 255, 256, we find

$$\alpha = 20^\circ$$

and from the equation $\tan \beta = \frac{h}{l}$ (§ 161, page 203).

$$\tan \beta = \tfrac{10}{20} = \tfrac{1}{2} = \cdot5$$
$$\text{or } \beta = 27^\circ$$

It is next necessary to determine the total weight W of the bridge and its load.

This, as noted in § 159, page 198, consists of 5 principal items :—

(1) The main ropes.
(2) The suspenders.

(3) The roadway.
(4) The ironwork.
(5) The load.

(3) The weight of the roadway and woodwork can be determined at once by simple calculation; suppose this work out to 9,320 lbs.

(4) The ironwork is similarly determined by simple calculation; suppose this to amount to 365 lbs.

(5) The live load. A fair allowance for this is 40 lbs. per square foot or 180′ × 4′ × 40 lbs. = 28,800 lbs. for the whole bridge.

To determine (1) and (2) it is first necessary to draw an elevation of the bridge on a fairly large scale, and measure off the actual length of iron wire required for each main rope and suspender, allowance being made in the latter case for the attachments.

This will be found to be about 185 feet each for the main ropes, and about 500 feet in all for the 35 pairs of suspenders with their attachments.

A few minutes' rough calculation shows the weight carried by each *pair* of suspenders to be—

	lbs.
Deodar wood about 6 cubic feet, at 40 lbs. per cubic foot	=240
and live load on an area of 5 feet × 4 feet = 20 square feet at 40 lbs. per square foot	=800
and say 10 lbs. for the wires themselves .	= 10
TOTAL .	1,050

or 525 lbs. strain on each wire.

A one inch iron wire, the thinnest given in the table in § 159, page 202, will carry 650 lbs. safely.

One inch wires may therefore be assumed for the suspenders, weighing ·14 pounds per running foot.

It now remains only to determine the dimensions and weight of the main ropes.

The weight of the other 4 items is—

Suspenders.		Roadway.		Ironwork.		Live load.
70	+	9,320	+	365	+	28,800

$= 38{,}555$ lbs.

and the length of the main ropes is 185 ft. each or 370 ft. in all.

Now, since the angle α is small, the tensions of the main ropes H and T are nearly equal, and the weight of the main ropes is but a small proportion of the whole load carried by them,

$$\text{and since } H = W\frac{x}{16y} = \tfrac{3}{4}\,W \text{ (Equation (3), page 200)}$$

because $x = 180$ and $y = 15$ (see conditions given on page 212, § 166), the strain on each of the main ropes will be about 30,000lbs. Referring to the table of weights and strengths of ropes (page 202) we see that this is about twice the strength of a 5″ iron wire rope. Let us try the effect of adopting a double line of 5″ iron wire rope for each of the main ropes.

Then the weight of this rope is—

$$2 \times 370 \times 3{\cdot}62 = 2{,}679 \text{ lbs.}$$

adding this to the weights above found.

W the whole weight of the suspension bridge + live load is equal to

$$= 41{,}234 \text{ lbs.}$$

$$\text{and } H = 30{,}925 \text{ lbs.}$$

$$\text{and } T = H \operatorname{Sec}\alpha = 30{,}925 \times 1{\cdot}064 = 32{,}904 \text{ lbs.}$$

The strain that can be safely supported by a double line of 5″ wire rope—

$$= 2 \times 16{,}240 = 32{,}480 \text{ lbs.}$$

which is almost the same as the actual tension T.

A double line of 5″ iron wire ropes may therefore be safely adopted for each of the main ropes.

Checking again the strain on the suspenders as in the original calculations—see § 160, page 203 formula (6).

$$T_s = \frac{W'}{2\,(n+1)}$$

$$W' = 38{,}555 \qquad n = 35$$

$$T_s = \frac{38{,}555}{72} = 535 \text{lbs.}$$

which is well within the strength of a 1″ rope.

The anchorage being effected by attachment to stanchions leaded into the rocks, these stanchions are exposed to a shearing strain = T

= 32,904 lbs. where the stanchion leaves the rock.

The dimensions of the stanchion must be calculated to resist this strain.

The shearing strain for wrought iron being limited to 10,000 lbs. per square inch.

The stanchions must have a section of not less than $\frac{32{,}904}{10{,}000} = 3{\cdot}29$ square inches.

∴ Wrought iron bars 2½″ in diameter will be suitable.

Strains on the Standards.

The standards may be supposed to be vertical posts of Sissoo *Dalbergia Sissoo*) wood sunk into the ground, and built up with masonry to the road level—

To determine their required dimensions;

The forces causing strains on a pier are—see § 164, page 207 *et seq.*—a vertical force $v = T \sin \alpha + T \sin \beta$

$$= 32{,}904 \times {\cdot}342 + 32{,}904 + {\cdot}454$$

$$= 26{,}192 \text{ lbs.}$$

and a horizontal force $h = T \cos \alpha - T \cos \beta$

$$= 32{,}904 \times {\cdot}940 - 32{,}904 \times {\cdot}891$$

$$= 1{,}612 \text{ lbs.}$$

acting at the top of the post.

The maximum working compressive strains to which Sissoo wood should be subjected is 1,000 lbs. per square inch.

Assume a section of 12″ × 8″ for the post.

The strain to which the beam is subjected owing to the vertical force—see formula (10), page 210—

$$p_v = \frac{26,192}{96} = 273 \text{ lbs. per square inch,}$$

and the maximum compressive srain to which is it subjected owing to the horizontal component—see formula (11), page 210—

$$p_h = 1,511$$

and the maximum strain to which the wood is subjected

$$p_s = p_h + p_v = 1,784 \text{ lbs. per square inch,}$$

which is too much; therefore 12″ × 8″ is not a sufficient section.

· Try a section of 15″ × 10″

in this case $p_v = 175$, $p_h = 774$ and $p_s = p_v = p_h + 949$ lbs. per square inch, which is well within the limit.

15″ × 10″ standards may therefere be adopted.

The remaining portions of the bridge do not require calculation.

§ **167.** The various forces acting on different portions of the bridge may be determined graphically as follows :

Let A be the head of a post, A B. A portion of pier AB as far as J only is shown in the figure.

Through A draw the horizontal line CAD.

Draw the lines AE, AF making the angles α and β with AC and AD respectively. In the case under consideration these are 20° and 27°.

FIG. 103.

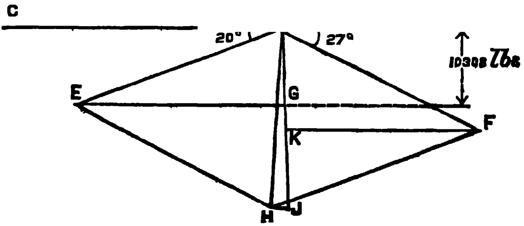


Figure 103 is a diagram to show how the strains on the different parts of a suspension bridge may be determined graphically. The construction of figures is fully described in the letterpress. (Scale 20,000 lbs. = 1 inch.)

On AJ set off A G= $\frac{W}{4}$ (one quarter of the weight of the bridge) on any convenient scale.

Draw GE horizontally to meet AE in E.

Make AF = AE and complete the parallelogram EAFH.

Draw HJ and FK perpendicular to AJ (AG produced).

Then AG=$\frac{W}{4}$ = in this example . . 10,308 lbs.

Then by direct measurement we find that EG = H, the horizontal strain on main rope at centre of span . . = 30,925 „

AE = T, the strain at the top of a pier . . . . . . = 32,904 „

AF = AE = T = tension of backstay = 32,904 „

AH = the resultant force on the top of a pier . . . . . = 26,252 „

AJ and HJ on the vertical and horizontal component of that force . . = 26,192 and 1,612lbs. respectively.

FK and KA are the horizontal and vertical components of the pull on the anchorage . . . . . = 29,318 and 14,938 respectively.

SECTION VI.—THE CANTILEVER BRIDGE.

§ 168. A cantilever bridge resembles a suspension bridge in so far as it requires no intermediate supports; and that its construction is consequently quite independent of the nature of the obstacle to be crossed. Bridges built on this principle can be constructed of very large spans, if made of sufficiently strong materials; but the consideration of such structures is far beyond the scope of this work. The bridge essentially consists of two counterpoised or weighted arms, built out from either side of the obstacle to be crossed. The longitudinal beams which carry the central portion of the roadway of the bridge, rest on the free ends of these arms, and are supported by them.

FIG. 104.

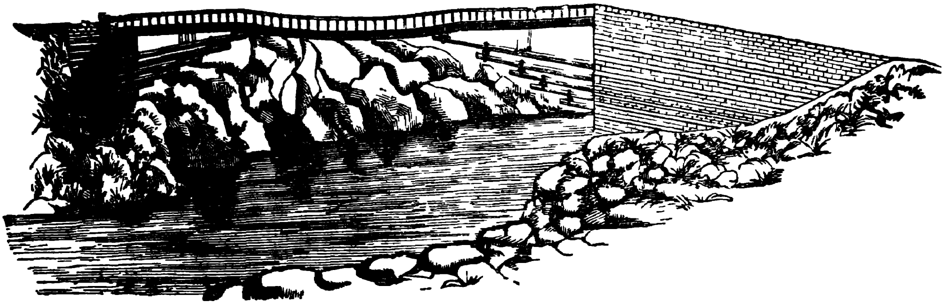


Figure 104 is a drawing of the Dilasni cantilever bridge, Kulu District, reduced from a photograph taken by Lieut.-Colonel St. G. Gore, R.E., Superintendent of Trigonometrical Branch of the G. T. Survey, Dehra Dun. The abutments are made of dry rubble masonry strengthened by horizontal wooden frames introduced at intervals. The total length of the bridge from one abutment to the other is 150 ft. The portion of the bridge which is supported by the arms built out from the piers being 64 ft. and the two side spans 43 ft. each. The roadway of the bridge is not quite horizontal having sagged in the middle.

Figure 104, which represents a cantilever bridge over the Beas river in Kulu, North-West Himalayas, shows very clearly the construction of the two counterpoised arms which support the central portion of the roadway of the bridge itself. The different beams are built out of either abutment to form an arm, on the free end of which longitudinal beams, which support the central span rest, are rigidly connected one with the other. They form, for all practical purposes, one beam, the centre of gravity of which is on the abutment side of the geometrical centre of the system of beams which form the arm. The portions of the stone abutments which rest on the ends of the beams embedded in them constitute the counterpoise, which enables their free ends to support the weight of the central portion of the roadway. The total length of the bridge measured from the face of one abutment to the face of the other is 150 ft., the central span, supported on the free ends of the arms built out from the abutments being about 64 ft. long. The longitudinal beams which carry the central span were not quite strong enough to bear the working strain to which they were submitted, and have, in consequence, sagged in the middle. They could have been strengthened without materially adding to their weight by the addition of iron rods as described in § 129, page 152.

Each longitudinal beam consists of three sections, one section stretches from the end of one abutment (see fig. 104, page 218) to one of the ends of the counterpoised arm. The second, the central portion, rests on the free ends of the counterpoised arms; while the third section connects the free end of the other counterpoised arm to the further abutment. In the figure the two end sections of the main longitudinal beams are supported at their centres, by posts resting on the top beams of the counterpoised arms, and are in this way very materially strengthened and stiffened.

As is often the case in the hill streams which have to be bridged in India, the bank of the stream on one side of the bridge is much higher than that on the other; and an abutment has been constructed on the lower bank so as to make the roadway of the bridge horizontal. In the bridge shown in fig. 104 this abutment was not made quite high enough, and the roadway of the bridge is in consequence not quite horizontal, but slopes towards the side on which the high abutment has been constructed.

The abutments of such bridges, in the lower ranges of the Himalayas, are constructed of dry rubble strengthened by wooden frames placed horizontally, at regular intervals from each other. The foundations and lower parts of the abutments are made of the largest blocks of stone that can be brought on to the site of the bridge. Abutments thus constructed have been found to stand where masonry foundations (small stones set in lime mortar) have been carried away by the force of the stream in flood. The faces of the abutment are battered on all sides, so as to increase the area of the base, and in so doing to add to its strength.

The gradient of the approach to the bridge from the lower bank of the river is steep, but can be made more gentle by lengthening the abutment itself.

The cantilever system of bridge is very useful when the obstacle to be crossed is too wide to allow of a single or trussed beam being used, and where the obstacle to be crossed is of such a nature as to preclude the use of any intermediate support. No scaffolding is required for its construction; the bridge may be built out from either side of the obstacle to be crossed at the same time.

Cantilever bridges are more suitable than suspension bridges, in localities which are far removed from civilized towns; because they can be constructed without the use of wire ropes. Rough cantilever bridges are commonly constructed entirely of wood and stone by the hill tribes of the Himalayas, in order to allow of the mountain torrents being crossed at all times of the year. Where a large boulder exists in the centre of the stream, the bridges are not infrequently of two spans, a central pier being placed on the large rock in the middle of the stream.

Cantilever bridges can be constructed of much larger spans than it is possible to build bridges supported on beams as described in section IV (pages 120 to 180).

They have a further advantage over bridges supported on beams, which are strengthened by the addition of a truss below; in that they afford a much larger waterway for the stream and there is consequently much less danger of their being carried away in an exceptionally high flood.

§ 169. Bridges of a temporary nature may be constructed on the cantilever principle, in order to facilitate the export of forest produce, or to open up communications. Figures 105 and 106 show in plan and sectional elevation a temporary bridge of this nature constructed by Forest Ranger Rama Dutt over the Tons river in December 1893, opposite to the Kuni Gadh, about 3 miles above Thadiâr. A temporary bridge was necessary at this point, in order to allow of the river being crossed for the purpose of inspecting the felling works, which were going on in the Chir Forests on the right bank of the river, as the nearest permanent bridge across the river was 3 miles lower down the stream.

The wood required for the construction of the bridge was obtained by felling some *chir* pine trees (*Pinus longifolia*) which grew near at hand. The main longitudinal beams were made out of stems of Chir pine, which were nearly cylindrical, and about 3 feet in girth. A very light roadway of the bridge was made of ½ inch planks of deodar, about 6 inches wide, 3 feet long. The bridge crosses the main stream of the Tons at its cold weather level, the abutments being built sufficiently high to allow of the passage of the water. The roadway is only 3 or 4 feet above the cold weather level of the water.

The counterpoised arms are made of two Chir pine poles and the counterpoise itself consists of large boulders brought from a short distance.

FIG. 105.

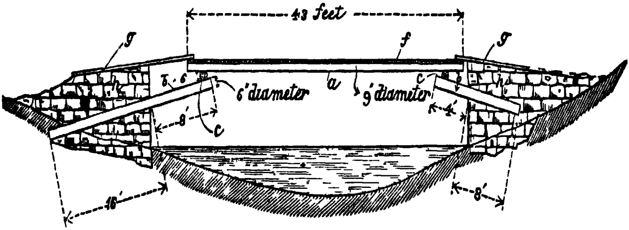


FIG. 106.

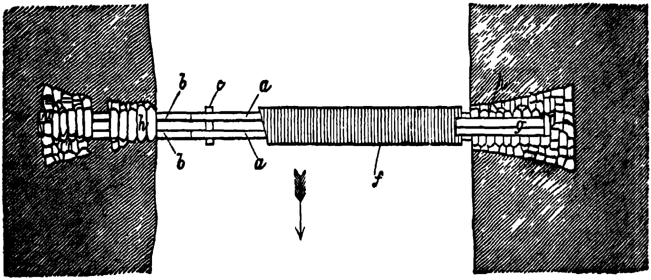


Figure 105 is a sectional elevation of a small temporary cantilever bridge thrown over the Tons river, about 3 miles above Thadiár. The wall plates under the arms (b, b) *in the abutments have been omitted (Jaunsar Forest Division).*

Figure 106 is a plan of the same. The planking has been left out on the left-hand side of the bridge, to show how the bridge timbers are arranged, and how the counterpoise (which is in this case large boulders) is placed on the arms supporting the longitudinal beams which carry the roadway.

a, a *are the longitudinal beams ;* b, b *the arms ;* c, c *the cross pieces on which the longitudinal beams rest ;* f *the planking of the roadway of the bridge ;* g, g *planks leading from the abutments to the bridge proper ;* h, h, *the stones which form the counterpoise. (Scale 12 feet = 1 inch.)*

The bridge is only meant for use during the cold weather, and will be removed before the river rises owing to the melting of the snows. It cost R20 only to erect.

§170. PRINCIPLES OF CONSTRUCTION.—In the cantilever form of bridge, beams are built out from either side of the obstacle to be crossed, until the space left between the free ends of these systems of beams is sufficiently small, to allow of its being spanned by single, simple or trussed beams. The beams of which the arms (which are built out from the sides of the obstacle to be crossed) are composed are securely fastened to each other; and may be considered, for all practical purposes, as compound beams. The system of beams which make up an arm is *counterpoised*, *i.e.*, weighted at one end, so as to allow of the longitudinal beams which carry the central portion of the roadway of the bridge, as well as the roadway itself, being supported; in a position of rest, on the projecting ends of the two arms which are built out of the abutments, or the sides of the obstacle to be spanned.

The actual amount of the weight, which can be supported by the systems of counterpoised beams of which the arms are composed, depends upon—

(1) the distance (measured horizontally) which the arms project beyond the face of the abutments,
(2) the amount of the weight of the counterpoise added and the distance of its centre of gravity from the outer face of the abutment,
(3) the size of the beams used and their transverse strength.

The farther removed the centre of gravity of the counterpoise is from the face of the abutment, the greater will be the weight which the free ends of the arms can support.

The greater the horizontal distance between the free ends of the arms, which are built out from the abutments, and support the longitudinal beams of the bridge, and the heavier the roadway, the greater will be the bending moment on the arms which project from the abutments and support the central portions of the bridge.

Those portions of the abutments upon which the counterpoised arms rest, must be very strongly and solidly built, and must rest on the most stable foundations that the nature of the ground will allow of. It is essential that the portion of the abutments upon which the cantilever arms actually rest, is sufficiently strong to bear the pressure which it has to support, without yielding; as, if these portions of the abutments are too weak, the whole bridge will fail.

If the abutments are properly constructed, the force which will be necessary to displace the counterpoise, would be much greater than that which would rupture the beams of which the projecting arms are composed.

The question of the best proportions between the different parts of a cantilever bridge are discussed in the next paragraph.

§ 171. CONDITIONS OF EQUILIBRIUM—The central beam and the two cantilever arms which support it, should be so designed, that each beam in the bridge will be subjected to the same greatest bending moment, if all the beams are of the same sectional area. If the scantlings used in the construction of the central beam and its two cantilever supports are of different sectional areas, the several parts should be constructed, so that each beam is subjected to a straining action proportional to its strength.

The amount of weight which each beam will have to carry depends upon its sectional area and the distance between the points at which it is supported.

The number of individual beams by which the central portion of the roadway (A C B, fig. 107) is supported may, or may not be equal to the number of beams in each of the cantilevers DA, BE.

Let N_2 = the number of beams which support the central portion of the roadway ACB;

and N_1 = the number of beams in each of the cantilevers DA, BE;

and assume that all the beams used are of same scantling.

Let L = the total span of the bridge in feet;

L' = the length of the central beam;

l = the length of each of the cantilever supports

then $L = L' + 2l$.

Let C be the centre of the span.

FIG 107.

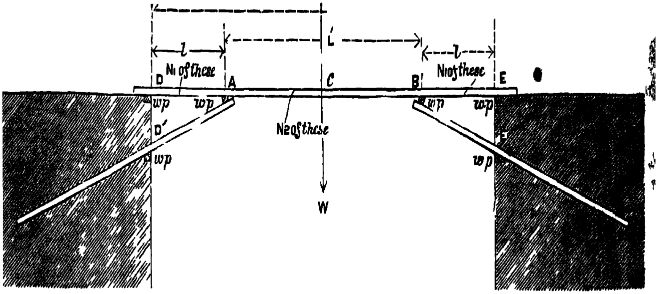


Figure 107 is a diagram to illustrate the forces acting on the different parts of a cantilever bridge, for the determination of the best proportion between the length of the central beam A C B and its cantilever supports AD, BE   The central beams ACB rest on the ends of the cantilevers AD and BE   The lateral beams BE, AD rest, partly on the free ends of the cantilevers, and partly on the abutments   w p, w p are wall plates   There are N_2 central beams, and N_1 lateral beams   L is the total span of the bridge and l the length of the lateral beams   C is the centre of the span and W is the load to be supported.

First let W = the total load to be supported and assume that it is a concentrated load

When it is at the centre of the span, the maximum bending moment on the portion A B will be at C, and the moment at C will be

$$M_c = \frac{W}{4}(L-2l)$$

that is, the amount of the bending moment on each beam (there are N_2 of them) will be

$$\frac{W}{4 \times N_2}(L-2l)$$

when the load W has shifted to A.

The total maximum bending moment at D,

$$M_d = W \times l$$

or the total maximum bending moment on each beam of the cantilever is

$$\frac{W \times l}{N_1}$$

Then, for equality of bending moments of each individual beam in the central portion and in the cantilevers

$$\frac{W}{4 N_2} (L-2l) = \frac{W\ l}{N_1}$$

or dividing by W

$$\frac{L-2l}{4 N_2} = \frac{l}{N_1}$$

or $$l = \frac{N_1}{N_2} \times \frac{L-2l}{4}$$

put $\frac{N_1}{N_2} = K$

then $$l = \frac{K}{4} \ (L-2l).$$

If $K = 1$ then $l = \frac{L - 2l}{4}$ or $l = \frac{L}{6}$

If $K = \frac{3}{2}$ then $l = \frac{3}{8} (L- 2l)$ or $l = \frac{3L}{14}$

If $K = \frac{4}{3}$ then $l = \frac{L - 2l}{3}$ or $l = \frac{L}{5}$

that is to say, if the number of beams in each cantilever are equal to the number of beams which support the central portion of the span, the length of each cantilever should be $\frac{1}{6}$ of the span and the length of the central portion $\frac{2}{3}$ of the span.

If there are 3 beams in each cantilever and only 2 beams supporting the central portion of the roadway, then the length of each cantilever should be $\frac{3}{14}$ of the span and the central portion $\frac{4}{7}$ of the span.

If there are 4 beams in each cantilever and only 3 beams supporting the central portion of the span, then the length of each cantilever should be $\frac{1}{5}$ of the span and that of the central portion $\frac{3}{5}$ of the span, and so on.

Next, suppose that the weight carried by the bridge is uniformly distributed, the amount of it being w per foot run, then the total bending moment at c,

$$M_c = \tfrac{1}{8} w (L - 2l)^2$$

or the maximum bending moment on each beam supporting the central portion of the roadway (there are N_2 of these)

$$= \frac{w}{8 N_2} (L - 2l)^2.$$

The total bending moment at A,

$$M_a = \left\{\tfrac{1}{2} wl + \tfrac{1}{2} w (L - 2l)\right\} l$$

$$= \frac{wl}{2} (L - l)$$

or the total bending moment on each beam in the cantilevers (there are N_1 of these)

$$= \frac{wl}{2 N_1} (L - l).$$

Then for equality of bending moments of each individual beam we have

$$\frac{w}{8 N_2} (L - 2l)^2 = \frac{wl}{2 N_1} (L - l)$$

or $$\frac{N_1}{N_2} \times \frac{w (L - 2l)^2}{4} = wl (L - l)$$

put $\frac{N_1}{N_2} = K$ and divide by w, then

$$K\frac{(L - 2l)^2}{4} = l (L - l)$$

If $K = 1$ we get $(L - 2l)^2 = 4l (L - l)$

or $(L - 4l)^2 = 8l^2$

or $L - 4l = 2l \sqrt{2}$

or $l = \frac{L}{2 (2 + \sqrt{2})} = \frac{L}{6{\cdot}828}$

If $K = \frac{3}{2}$ we get $\frac{3 (L - 2l)^2}{8} = l (L - l)$

or $3 (L^2 - 4lL + 4l^2) = 8l L - 8l^2$

or $L^2 - \frac{20l L}{3} + \frac{20}{3} l^2 = 0.$

Solving this equation we find (taking the + sign)

$$\text{that} \qquad l = \frac{L}{5{\cdot}441}$$

$$\text{If } K = \tfrac{4}{3} \text{ we get} \qquad \frac{4}{3}\,\frac{(L-2l)^2}{4} = l\,(L-l)$$

$$\text{or } L^2 - 4l\,L + 4l^2 = 3l\,L - 3l^2$$

$$\text{or } L^2 - 7l\,L + 7l^2 = 0.$$

Solving this equation we find, taking the + sign, that

$$\text{or } l = \frac{L}{5{\cdot}791}.$$

assuming half the load concentrated and half distributed, the proportion of $\frac{l}{L}$ should be made midway between the two sets of values just found.

§ **172.** In the above considerations we have assumed that all the beams used in the construction of the central portion of the span, and also of the cantilever arms, are of the same scantling. But in practice the largest beams are used for the central portion of the span, while beams of smaller size are used in the construction of the cantilever arms AD′, BE′; and if this be the case, the relation between l and L, the length of the overhang of the cantilever, and the total length of the unsupported central portion of the span, will not be that shown in § 171, but will vary with the difference in size of the beams used, as is shown in the following equation.

As before, let l = the overhang of the cantilever, suitable for a section, equal to that of the beams in the central portion of the span (breadth b inches and depth d inches).

and l_1 the overhang of the cantilever when the section of the beams used in its construction are a breadth of b_1 inches and a depth of d_1 inches,

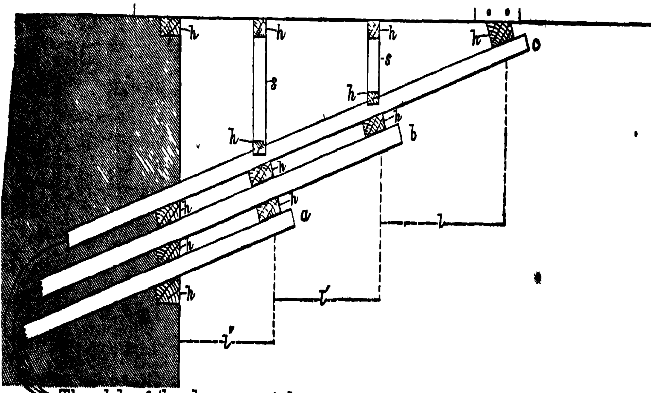
then

$$\frac{l_1}{l} = \frac{b_1\,d_1^2}{b\,d^2}$$

§ **173.** The cantilever arms may be fortified by being under supported, as shown in Fig. 108. In such a case the lengths denoted by L and l in the foregoing expressions are to be measured as shown in Fig. 108, and the total overhang of each cantilever may be made much greater.

The ratio of l to L should be as before, l' should be a little less than l and l'' less than l', and so on.

FIG. 108.



The whole of these beams are not shown

Fig. 108 is an elevation of one cantilever support of a cantilever bridge, to show how the cantilever can be fortified and lengthened. The total span is, as in Fig. 107, denoted by L. The end of the central portion of the bridge rests on the series of beams c, *which are in their turn supported by the series of beams* b, *which similarly rest on the series* a. *The beam A D, which carries the roadway is strengthened by two supports S, S. The ends of the series of beams* a, b, c, *which are embedded in the abutment, are not shown;* h h h h, *etc., are wall-plates.*

§ 174. In the foregoing calculations the number of beams in each of the tiers a, b, c, of which the cantilever arms are made up is equal.

The structure will be made much stronger if the number of beams in each tier is increased by one as we descend. Thus if there are 3 beams in the top tier (*c*, Fig. 108), there should be 4 beams in the second row (*b*, Fig. 108), 5 beams in the third row (*a*, Fig. 108), and so on. If this procedure be followed, the strain on the lower members of the cantilever arms will be less (supposing the beams used to be of one and the same scantling); and the area of pressure on the abutment will be greater, and consequently the pressure per unit of area will be proportionately less.

If the number of beams in each tier of the cantilever arm be increased as suggested, the amount of overhang of each tier may be *l*, and not decreased, as would be necessary were the number of beams in each tier the same.

SECTION VII.—MASONRY BRIDGES AND CULVERTS.

§ 175. The various forms of arch employed for stone-work and brick-work bridges have been mentioned in Volume I, Part II, Section III, page 181, *et seq.*

Masonry bridges should be constructed only where unyielding foundation beds can be obtained. In cases where a serious amount of uneven settlement may occur, a girder bridge is preferable; settlement may cause cracks in an arch, and endanger its stability; whereas a girder can subside to some extent, without any serious decrease in its strength or utility, and remedial measures can generally be easily applied.

§ 176. CONSTRUCTION OF AN ARCH-RING IN BRICKWORK.—The arch is commonly built up in concentric half-brick rings, that is, bricks are laid as stretchers to the intrados surface, the number of the successive rings depends upon the span and the load on the arch; the radial joints in the successive rings only coincide occasionally, and the practice is sometimes adopted of inserting, at the place of coincidence, a header brick which will tie the two courses together. Unless the arch is built with the greatest care, using strong bricks and making thin and well-filled mortar joints in cement, the utility of these bonding bricks is uncertain, as they are generally found to be broken when an arch is taken down.

An arch may also be built with the bricks laid as headers and stretchers to the intrados; on the vertical face of the arch-ring they also appear as alternately headers and stretchers. In this form of arch-ring, the radial side joints of the bricks are continuous; and consequently in arches of small radius, built with parallel-sided bricks, the extrados will show a wide open joint which should be well packed with mortar and pieces of slate. This is seldom properly executed, and, consequently, the concentric half-brick rings are commonly built with parallel-sided bricks for a radius of 8 feet and upwards. For the best work in arches of less than 10 feet radius, and for ordinary work of less than 4 feet radius, specially moulded radial bricks should be used, or ordinary bricks with their sides roughly chopped radial with the bricklayer's axe; these are termed *rough* arches, to distinguish them from the *plain* arches built with rectangular bricks.

In the roughest brickwork, ordinary bricks are built in arch-rings of 3 feet radius, but such work is not strong. Taking the distance between centres of mortar joints at 3 inches in ordinary brickwork the increase in width of joint at the extrados, over that at the intrados in a half-brick ring is, for 3 feet radius 0·38 inches, for 4 feet radius 0·30 inches, for 6 feet radius 0·19 inches, and for 10 feet radius 0·11 inches approximately.

In stonework, the arch stones are either roughly chopped or chiselled to shape, with radial sides at right angles to the intrados; if practicable, one stone should penetrate completely through the arch-ring from intrados to extrados; if it is necessary to use more than one stone in each voussoir (or arch-stone) the joints in each successive voussoir should alternate. In better work the contact faces of the voussoirs are dressed true to radial shape, so that the stones of the arch-ring are fitted together closely, with thin well-filled mortar joints of uniform thickness. The keystone is generally rammed down into place by mallets, to tighten up and make compact the joints in the arch-ring on either side. There is no advantage, except in appearance, gained by making the keystone project below the intrados.

For spans up to 20 feet, bricks make usually stronger arches than ordinary rough cut stone blocks; but if each voussoir block is cut accurately to shape in a hard, tough stone, the arch will be stronger but more costly. Bridges built mainly of stone blocks may have a brick arch-ring, to save expense of accurately-shaped voussoirs.

Where cut-stone or bricks are not available, solid concrete arches may be built. The span of a concrete arch need not necessarily be less than one in brick or stone; and for forest work limited to short spans, concrete can be used freely, but special precautions must be taken to secure good materials, thorough mixing in proper proportions, and careful deposition of the concrete, to form a dense compact mass in the arch-ring and abutments.*

The arch-ring should be built up rapidly and evenly from each skewback; while being built it rests on a rigid centering or frame-work. As soon as the arch is completed and the mortar has begun to set, the supporting centering should be lowered uniformly to a very small extent, without shocks causing any disturbance of the masonry, and this slight lowering is repeated at short intervals of days, according to the setting of the mortar, until the arch carries itself, and no longer rests on the centering; the object being to allow the stones or bricks in the arch to settle down gradually to firm bearing surfaces in the joints.

If the arch is built of finely-dressed stones with thin well-filled cement joints, the centering may be slackened down shortly after the completion of the arch; but with common stone or brick arches with coarse mortar joints made with ordinary lime, the slackening should be delayed till the mortar is beginning to set, and then carried out gradually, the complete removal of the support being delayed till the mortar has set hard.

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* For further information on the subject of mixing concrete and the qualities of lime and cement, *see* "Lime and Cement," by A. H. Heath, A.M.I.C.E., (London, E. and N. Spon.)

In the case of an arch carrying an earthen bank, the centering should not be finally removed until the newly deposited earth has settled down into a fairly compact mass.

The springing line of the arch should be from 6 to 8 feet above flood level in a navigable, and 2 to 3 feet above, for a non-navigable, running stream; over non-flowing water it may be at water-level or even a little below.

RISE IN SEGMENTAL ARCHES.—For spans not more than 15 feet, a rise of $\frac{1}{6}$th the span should be given, while for spans more than 30 feet a rise of $\frac{1}{4}$th the span is allowable. For spans intermediate to these a rise between these limits should be given. In ordinary cases, arches of from 30 to 40 feet span are recommended in preference to larger arches, as they are comparatively cheaper, are more easily constructed, require less elaborate and expensive centreings, and standard patterns can be followed.

§ 177. THICKNESS OF THE ARCH-RING.—Formulæ for the calculation of stresses on an arch-ring and for determining the location of the line of least resistance, are given by Rankine and other authorities on the theory of the arch; and are discussed in Professor I. O. Baker's book,* "A Treatise on Masonry Construction;" but, as there stated, the best theory is only an approximation, and the stability of an arch does not at present admit of exact mathematical solution, but is to some extent an indeterminate problem. The stability of an arch depends upon (1) the condition of the loading (both live and dead load); (2) the bonding of the masonry, the mortar used, the quality of the materials, and the workmanship; (3) the manner of constructing and of striking the centering; (4) the stability of the abutments and the uniform rigidity of their foundation.

In forest works, the building of arches is generally confined to small spans and single arches, and the masonry will not be superior to the ordinary class; it is therefore deemed inadvisable to enter into the theory of the stability of arches, and only to give some empirical formulæ for ascertaining the depth of an arch-ring, the thickness of an abutment and of a wing wall.

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* "A Treatise on Masonry Construction," by Professor I. O. Baker, C. E. (John Wiley and Sons, New York.)

Trautwine's formula for the depth of an arch at the crown, is for first class cut-stone arch

$$d = \frac{\sqrt{\frac{r + s}{2}}}{4} + 0{\cdot}20$$

where d = depth at crown in feet,
r = radius of curvature of intrados in feet,
s = the span in feet.

For second class work add to this depth one-eighth, and for brickwork or rubble masonry, add about one-third.

Rankine* has given the following formulæ for the thickness of an arch at its crown :—

For a single arch $E = \sqrt{0{\cdot}12 \times r}$ feet.
For an arch of a series $E = \sqrt{0{\cdot}17 \times r}$ feet.

Where r = radius of curvature of the *intrados* (see Volume I, § 144, page 181) of the arch, and E = required thickness of the arch at the crown. r can be ascertained from the formula, $r = \frac{v^{2}}{s'}$ where v' is the rise and s' the half span. These formulæ were deduced from dimensions of good existing examples of arches.

These formulæ† apply where the ground is very firm and safe. In soft and slippery materials the thickness ranges from one and a half to twice that given in the above formulæ, that is, from $\sqrt{0{\cdot}27\, r}$ to $\sqrt{0{\cdot}48\, r}$.

The following table taken from Molesworth's Pocket Book of Engineering formulæ shows the thickness required at the crown of arches of radii of from 2—15 feet.

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* Madras Civil Engineering College papers, Part III, page 173.
† Rankine, A Manual of Civil Engineering, 16th edition, page 435.

Radius of curvature.	THICKNESS OF ARCH AT CROWN.		Radius of curvature.	THICKNESS OF ARCH AT CROWN.	
	Stone.	Brick.		Stone.	Brick.
Feet.	Feet.	Feet.	Feet.	Feet.	Feet.
2	·42	·56	7	·80	1·06
2½	·47	·63	8	·85	1·13
	·52	·69	9	·90	1·20
3½	·56	·75	10	·95	1·26
4	·60	·80	11	1·00	1·33
4½	·64	·85	12	1·04	1·38
5	·67	·90	13	1·08	1·44
5½	·71	·94	14	1·12	1·50
6	·74	·98	15	1·16	1·55

Segmental arches may be given a depth at the crown of from $\frac{1}{30}$ to $\frac{1}{35}$ of the span, or from $\frac{1}{26}$ to $\frac{1}{30}$ of the radius of the intrados. These proportions are derived from approved examples.

The pressure on an arch increases from the crown to the springing surface, and the depth of the arch-ring at the springing is commonly made 1¼ to 1½ times that at the crown, though for small arches, say 30 feet span and under, the greater depth is maintained throughout. An empirical formula states that the length, measured radially, of each joint between the joint of rupture (or springing) and the crown should be such that its vertical projection is equal to the depth of the keystone, or: $l = d$ sec. L; where l=length of the joint, d the depth at the crown, and L the angle the joint makes with the vertical.

For circular and segmental arches, v being the rise of the arch in feet and s the span*—

$$\text{if } \frac{v}{s} = \frac{1}{2} \text{ then } l = 2{\cdot}00\, d$$

---

* Masonry Construction, by Professor I. O. Baker, C.E. (John Wiley and Sons, New York.)

if $\frac{v}{s} = \frac{1}{6}$ then $l = 1{\cdot}40d$

if $\frac{v}{s} = \frac{1}{8}$ then $l = 1{\cdot}24d$

if $\frac{v}{s} = \frac{1}{10}$ then $l = 1{\cdot}15d$

if $\frac{v}{s} = \frac{1}{12}$ then $l = 1{\cdot}10d$

Empirical formulæ are founded on successful practice of widely varying character and differing conditions, consequently, the results given by different formulæ may not agree closely; the use of these formulæ does not absolve the bridge designer and builder from the exercise of his judgment and discretion.

§ 178. ABUTMENTS to bridges, where the roadway over the arch is approached by an artificial earthen bank, may be built as a rectangular mass of masonry, the longer side parallel to the over roadway; the rectangular mass is generally built up of thick outer walls, tied together by thinner transverse and longitudinal parallel walls; thus spaces or pockets are formed which may be filled with sand, gravel, broken stone, or weak concrete. This form of abutment is generally built for bridges of wide span and low rise of arch, requiring heavy and strong abutments.

A second form of abutment is commonly used when the arch crosses a deep ravine, or eroded water-course with high permanent banks; the foundations of the abutments may be seated some depth below the eroded surface and, consequently, still deeper below the surface of the adjacent non-eroded ground. A similar case occurs when a road or railway bridge is carried over a cutting with sloping sides.

The abutment may then be built U-shaped in plan, with return walls parallel to the axis of the over roadway, and these walls may be built with foundation beds stepped up the solid ground of the sloped bank of the ravine. In building these U-plan abutments, the face wall of the abutment is either built solid in graduated thickness, or may consist of a thinner face wall, at to 3½ feet thick, strengthened by buttresses. In building the return wing walls parallel to the axis of the over roadway the pressure of the earth between the walls is less than normal, as the walls are not far apart, and a selected, dry, compact material is used for filling; but the effect of the moving load and the consequent vibrations must be counteracted, and it is usual to build the walls of full dimensions as retaining walls. The returned walls must be well bonded into the abutment, and the included angle between each side wall and the back of the abutment should be filled up in solid well-bonded brickwork for a distance of about 2½ to 3 feet in each direction from the imaginary inter-section. Specially moulded bricks are used where the angle filling is bonded into the back of the abutment and wing wall; they are placed with the longer limb alternating in position. In cases where the thorough bonding and filling of the angle have been omitted, cracks in the brickwork have developed, separating the returned wing walls from the abutment.

A third form of abutment is built, when the greater part of its height is above natural ground surface, and when the earthen slopes of the over roadway must not encroach upon the passage-way beneath the arch. In this case, each earthen slope is upheld by a wing wall, commonly built as a straight battered wall gradually receding from the line of the face of the abutment; they are termed splayed wing walls. Sometimes these walls end before the toe of the slope is reached, at say 3 to 4 feet height of slope, and are terminated by a square newel, the earth of the slope then comes round the newel and in front of the end of the wing wall as a portion of a cone. For a bridge over a stream, the wing walls should be carried to the extreme limit of the toe of the slope of the overbank, and the angle of splay receding from the line of the abutment face, may be between 10° and 12°. For a wing wall, where there is no water-course, the angle of splay is commonly between 20° and 30°; the greater the angle the longer is the wall and the heavier is the lateral pressure. Splayed wing walls are commonly built with their tops inclined, parallel to, or agreeing with, the surface of the slope of the earthen bank; or they may be stepped at regular intervals, conforming to the slope.

Abutments and wing walls are commonly built with off-setted backs, the weight of the earth resting on the off-sets, tending to increase the resistance to lateral thrust. Similarly in rubble masonry, long stones may be built to project beyond the back of the wall. Ample drainage of the earth at the back of the wall must be provided by weep-holes through the walls; these are either gaps 3 to 4 inches wide left in the course of masonry or are drain-pipes built in, one to every 3 or 4 square yards of face of wall.

At the back of the wall, a small mass of puddled clay is sometimes placed to lead percolating water to the weep-hole or a vertical backing of coarse gravel or of broken stone, one to two feet thick, is formed next to the wall when the earth of the embankment is clayey and retentive of moisture. Clay should not be used as a backing to an abutment or to a wing wall, and in cases where the approach embankment must necessarily be made of clay, it is advisable that the top of the clay bank should not extend nearer to the back of the abutment than twice the height of the abutment above the solid ground. The backing to the abutment should be of the best procurable material, dry, compact, and unalterable by wetness or exposure, broken stone, broken brick, gravel and gravelly soils are suitable; and where special precautions are necessary the material should be deposited in 12-inch layers, well rammed and sloping downwards away from the abutment,

An abutment to an arched bridge is commonly built with a vertical face; sometimes a batter of 1 in 10 to 1 in 8 is given. The thickness of an abutment at any horizontal plane depends upon the lateral thrust of the loaded segmental arch, and the height above the ground; the loaded earthen bank supported by the back of the abutment may also require consideration. Increase in thickness to a vertical-faced masonry abutment is given by offsets at the back; a common proportion is 4½ inches to 6 inches added for every 6 feet in height, or in stonework 6 inches in every 10 feet. In concrete a batter of about 1 in 8 may be given.

§ 179. Various methods of ascertaining the thickness of the abutments at the springing are given in Professor Baker's treatise on masonry construction (see footnote on page 235).

but for forest work, where the bridges are of small span and size, empirical formula for the dimensions will probably suffice.

Trautwine's empirical formula for the thickness of the abutment at the springing (t) is for all arches.

$t = (0{\cdot}2\,r + 0{\cdot}1\,v + 2{\cdot}0$ in feet) where r is the radius, and v the rise of the arch in feet.

For rough rubble abutments add 6 inches to the thickness given by this formula.

For small bridges, and large culverts beneath railroads and subjected to jarring vibrations, abutments are, in many cases, built one-fourth to one-half thicker than given by the above formula.

The abutments of a single arch have to sustain the thrust of the half-arch which rests on it, unbalanced by the counterthrust of any adjoining semi-arch, and must, in consequence, be thicker than the piers. An empirical rule for the thickness of the abutments at the springing, is one-fourth of the span for arches up to 30 feet, and ⅕th span for larger arches.

The vertical sectional area of an abutment for a segmental arch may be designed as follows :—

FIG. 109.

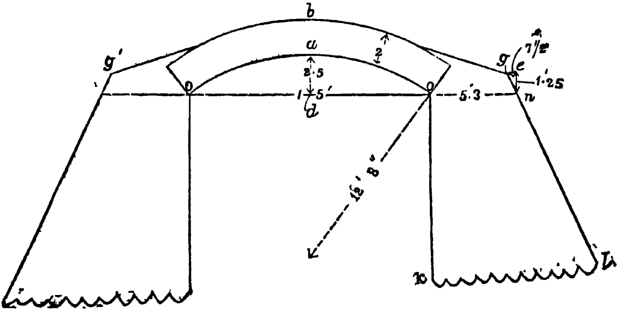


Figure 109 illustrates the process of designing the vertical sectional area of an abutment for a segmental arch. The span o o *is 15 feet. The rise* a d *is 2½ feet. The thickness of the arch-ring* a b *is 2 feet.* o n *laid off horizontally is 5·3 feet,* n e *at right angles to* o n *is 1·25 feet,* e g *is 7½ inches,* o k *is vertical, the direction of* n l *is obtained by joining the points* g *and* n, *and producing the line thus obtained.* (*Scale 8 feet = 1 inch.*)

Calculate the thickness of the abutment at the springing (t) by the formula given on page 239, and lay off that distance $o\ n$ horizontally from the springing line of the arch-ring; vertically above n set out $n\ e$ equal to half the rise of the arch. From e lay off horizontally $e\ g$ one-twenty-fourth of the span. Then the line $g\ n$ prolonged downwards will give the outline of the back of the abutment, whether stepped or battered, taking care that the thickness or width at base $k\ l$ is not less than two-thirds of $k\ o$ (the height of the abutment from the top of the footing-courses to the springing line).

The upper surface of the backing to the haunch f the arch may be obtained by drawing a line from g tangential to the extrados; or by finding an arc of a circle which will pass through g, b, and g' on the left abutment corresponding to g.

Another rule for t, the thickness of the abutment at the springing of the arch, is given as

$$t = 1 + 0{\cdot}04\ (5s + 4h)$$

where h is the distance from the springing line to the top of the foundation courses and s is the span.

Sometimes the height of the point e is three-quarters of the rise of the arch above the springing for a semi-circular arch.

Another rule is to draw the surface of the haunch backing tangential to the extrados, and at an angle of about 20° to the horizontal, or with a slope of 2¾ horizontal to 1 with the vertical. The backing is sometimes extended to cover the whole of a semi-circular arch and its thickness over the crown may be from 6 to 9 inches.

§ **180.** The semi-circular arch-ring requires more backing to the haunches than the segmental arch. This backing is often built solid, in horizontal courses for the flatter segmental arches, the profile of its surface transversely to the axis of the roadway above, being two or more reversed slopes, or W-pattern, to facilitate the diversion of percolating water from the brick-work surface; and 3 to 4 inch pipes built through the arch-ring just above the skewback, finally discharge the water. Or the pipes may be built in the pier or abutment, and finally discharge into the side drain of the road, or about one foot above the ground surface or flood-level. The surface of the backing and of the exposed arch-ring may be covered with an impervious coating of asphalt or of Portland cement, ½ to ¾ of an inch thick.

To diminish the mass of brickwork, and its weight, the haunch backing for adjacent arches, is often built as a series of parallel walls, extending from haunch to haunch over the piers, and these walls, connected by small brick-work arches, covering the space between them; they are called arched spandril walls.

§ **181.** An abutment with wing walls is sometimes built as a solid wall of graduated thickness; or a thinner face wall may be supported by projecting buttresses or counterforts at the back; the face wall may be of uniform thickness and the buttresses of graduated thickness.

The buttresses are commonly built at clear intervals of 3 to 5 feet, and may be 2¼ to 3 feet wide, the thickness of the face wall being 3 feet, the amount of projection of the buttresses at the footing courses, being made equal to one-fifth of the height of the wall, *plus* 2 feet, taking the nearest half-brick dimension.

The width of a counterfort may be taken as one-tenth the height of the wall, *plus* 2 feet.

For railway bridges of 26 to 30 feet span, practice gives examples of abutment feet walls 3 feet to 3¾ feet thick, and buttresses projecting 3¾ to 6 feet, and 2¼ to 3 feet in thickness, with a clear space between buttresses of 3 feet and 3¾ feet. The spaces are arched over with semicircular arches, the soffit of the buttress arch being at the springing-level of the main arch. The solid backing to the haunch of the main arch, starts at a point above the springing-line, about ⅓ of the rise of the arch. The space between the buttresses should be filled with rubble, broken stone, brick or gravel.

§ **182.** THE FOUNDATIONS of abutments and wing walls must be in sound, unyielding earth, strengthened, if required to be uniformly able to carry the load. Concrete (either of good hydraulic lime or cement) in thicknesses of 2 feet and upwards may, if necessary, be freely used to extend the area of the foundation beds. Dry rubble stone, in 6-inch layers, may be well rammed down into soft clayey soil until a thickness of 3 feet and upwards is made compact. Gravel and coarse sand may be similarly used. Equal care must be paid to wing wall and abutment foundations, inequality of settlement will cause disruption of the structure, and separation of parts. Abutment, wing and retaining wall foundations must be seated at a sufficient depth to prevent any lateral movement. There have been many cases of failure of such structures, due to shallow foundations offering insufficient resistance to lateral thrust. The requisite depth depends upon the character of the earth of the foundation trench and the intensity of pressure to be resisted ; it is rarely less than 4½ feet for a wall 10 feet high, and in many cases must be deeper. The foundation bed must be well drained and no percolating water permitted to gain access to it.

The ordinary thickness of a brick pier, measured at the top is $\frac{1}{8}$th of the span, for spans from 15 to 30 feet. The top of the pier must be shaped to receive the springings of the adjacent arch supported by it.

The constant load on a pier is the weight of the half-arch on each side, including the superstructure above ; and the direction of resultant pressure is vertical. When the resistance to crushing, per unit of area of the masonry of the pier is known, the area of the horizontal section can be estimated. In addition to the constant load, there is the live or moving load, which causes a lateral pressure on the pier, attains a maximum when the live load is at mid-span, and changes gradually to a vertical pressure when over the pier ; allowance must be made for this load. The practical construction of the pier must also be considered, the top of the pier must give room for the skewback surfaces.

§ 183. WING WALLS—are generally built with a face batter of 1 in 6 to 1 in 8 ; in masonry the larger and most regularly-shaped stones should be built in the face of wall, and the mortar joints should be at right angles to the face and be well filled. In dry (mortarless) rubble walls the face joints are commonly made horizontal for a depth of at least 9 to 12 inches, to prevent rain entering the inclined face joints and finding its way into the backing. The back of the wall at the top, for a depth of 3 or 4 feet, should be given a batter of at least 1 in 12 from the vertical and away from the face.

The thickness of such wing walls varies with the lateral pressure, and is generally made from ¼ to ⅓ the height of the wall measuring to the top of the footing-courses; the face of the wall having a batter of 1 in 6 to 1 in 12. This thickness is for the wall just above the footing courses, and, having fixed a convenient thickness for the top of the wall, according to the necessity of supporting a horizontal surfaced mass of earth or of supporting the slope of an elevated or surcharged bank: the back of the wall will be the inclined line joining these two points, or a graduated or stepped line giving this minimum thickness. In ground of average character the thickness is generally made one-third of the height and in no case of surcharged or exceptional heavy loading is it considered necessary, to make the thickness more than one-half of the height.

Approximate dimensions for retaining walls are given in the following table, where column A represents the angle (expressed in degrees to the horizontal) of repose of the earth backing of the wall; and column B gives the factor by which the vertical distance from the top of the wall to the footing-courses (*h*) is to be multiplied, to give the thickness at that point:

A	B
30	$h \times 0{\cdot}344$
32	$h \times 0{\cdot}331$
34	$h \times 0{\cdot}318$
36	$h \times 0{\cdot}305$
38	$h \times 0{\cdot}292$
40	$h \times 0{\cdot}280$
42	$h \times 0{\cdot}266$
45	$h \times 0{\cdot}247$

The thickness of the wall at the top is usually not less than 2 to 2½ bricks, and the nearest larger half-brick dimension is taken for the thickness; the back of the wall being narrowed in half brick steps at regular vertical intervals.

Another rule is Trautwine's; the thickness at the top of the footing-courses, of a vertical or nearly vertical wall sustaining gravel, sand or earth with level top surface, deposited loosely at back is—

for cut stone or best rubble in mortar .	35 per cent. of the distance from the top of the wall to the footing course.	
for good common rubble or brickwork .	40 per cent.	ditto.
for well fitted dry rubble .	50 per cent.	ditto.

If the backing to the abutment and wing walls is of a selected dry material, carefully consolidated in layers, either horizontal or sloping downwards away from the back of the wall, the thickness of the wing wall may be reduced. For sand and gravel, having little or no cohesion, full dimensions must be used ; also for backing of mixed soils liable to settlement, and when soils likely to slip (wet clays, etc.) are compulsorily used, the thickness may be increased by about one-eighth to one-sixth.

The thickness of a wing wall at the top is commonly not less than 1½ bricks, increasing rapidly by successive steps to 2½ to 3 bricks thick; in some cases, the top is made 2½ bricks thick, and graduated thicknesses succeed in regular order.

§ **184.** Figures 110, 111 and 112, pages 246, 247, show a good type of a masonry bridge designed and drawn by Mr. H. Western Hutchinson, A.M.I.C.E., who wishes it to be clearly understood that the drawings only represent a type, and that, although the design would be suitable for many places, it would not be advisable to erect such a structure without modifications in many other places.

This remark refers especially to the foundations. It is imperative that the foundations should be of such a description that they will not be undermined by the stream ; it therefore follows that the nature of the strata of the banks of the stream will in a large measure govern the design In some cases indeed, it will be found expedient to build the abutments on pile-work The *apron* has not been indicated in the drawing since its size and the nature of its construction will depend upon, and vary with, local conditions, and consequently, no definite general rules can be given on the subject The use of the *apron* is to protect the foundations of the wing walls and the abutments from being undermined by the stream, and this fact should be kept in mind when the *apron* is being designed.

Where the scour is considerable, it is always desirable to extend the *apron* for some distance beyond the wing walls both up and down stream

The thickness of the arch ring of any bridge that it is required to build, should be determined as detailed in § 177, page 233 The thickness of the abutments should be determined as described in § 178 page 236 The wing walls are practically retaining walls, and they should be designed as such, a thickness of 2 feet (for masonry) being given at the top of the wall and the thickness being increased by 6 inches at regular intervals of height as detailed in § 183, page 243 The construction of the abutment will be easier to build if the inner side is stepped down as shown in figure 110, page 246, instead of being carried down as the sloping line shown in figure 109 page 239

The splayed out wing walls *e* (Figs 110 and 111, pages 246 and 247) retain the earthen banks of the water-course on the up-stream and down-stream sides of the bridge They are built vertical, instead of battered and leaning against the bank, to give unobstructed approach to the archway If these retaining walls were battered, there wou'd be a projecting part of the abutment against which the current would impinge and form eddies

The foundations for the abutments, and those of the splayed retaining walls, must be seated on firm ground, below the bed of the stream. The foundation of the splayed wings may be at a shallower depth, or may be stepped up in firm undisturbed ground A parapet wall about 3 feet high is built over the arch and abutments on each side of the over roadway.

FIG. 110.

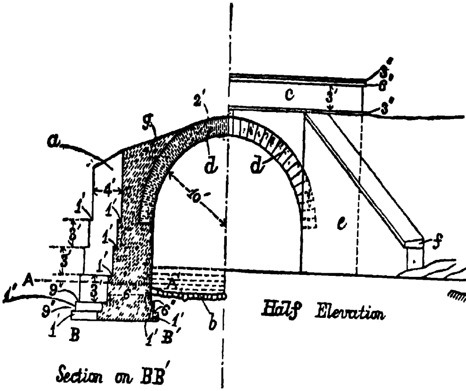


FIG. 112.

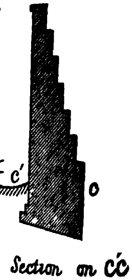


Figure 110 is a half-section, half-elevation of a good type of masonry bridge. The half-section is taken across B B (Fig. 111) and shows the abutment and arch-ring of the bridge only. The unshaded portion a *is the elevation of the counterfort* a *of the sectional plan, Fig. 111. The foundations must be carried below the scouring action of the stream. The paving of the bridge is shown at* b *with the water of the stream above it.*

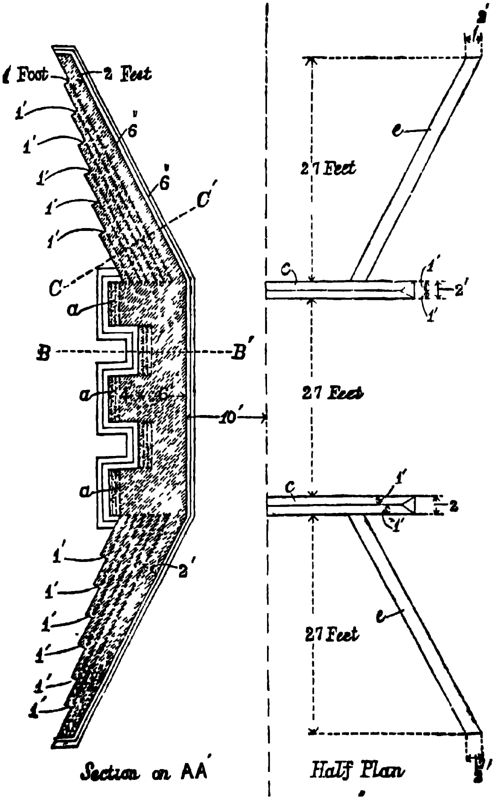
In the half-elevation (Fig. 110) the parapet wall c, *the arch-ring* d *and the wing wall* e, *are seen. The coping* f *of the wing wall is not shown in the sectional plan in Fig. 111.*

Figure 112 is a section through the wing wall e, *Fig. 110 along the line* $C\ C^1$ *of Fig. 111. It shows in detail the construction of the wing wall and how its thickness is increased by offsets at the back.*

Figure 111 is a half-sectional plan and half plan of the bridge. In the sectional plan the abutment (a, g, *Fig. 110) and wing walls are shown only, the arch-ring* d *is not shown. The abutment is strengthened by three counterforts* a, a, a

In the half-plan only the tops of the parapets and the copings of the wing walls are seen. (Scale $\frac{1}{14}$ *inch = 1 foot.)*

FIG. 111.


1 Foot
2 Feet
1'
1'
1'
1'
1'
6"
6"
C'
C
a
B
B'
a
4 × 6
10'
a
1'
1'
1'
1'
1'
1'
2'
2'
1/4
e
27 Feet
c
1'
2'
1'
27 Feet
c
1'
2
1'
27 Feet
e
2'
Section on AA'
Half Plan
Scale = 1 foot

The width of the arch is the width of the over-road, *plus* the thickness of the two parapet walls; which are generally not less than 1½ bricks or 2 feet of stone masonry thick.

To protect the bed of the stream under the archway from scouring action, which might endanger the foundations, a floor of brick on edge in cement, may be built about 2½ feet wide at each entrance of the arch, and the floor between is paved with stone blocks. The brick flooring often extends between the bank retaining walls on both sides of the bridge: the upper surface of the floor sloping downwards away from the arch, at the rate of 1 in 10; this portion of flooring is called the *apron.*

To protect the up-stream and down-stream edges of the apron from being undermined by the current, short rectangular timber piles 9 inches by 3 inches to 12 inches by 6 inches, according to the situation, may be driven down with their narrow edges in close contact, and their sides fitting closely to the edge of the apron, forming a curtain wall generally not less than 4 feet deep, and deeper if the ground be soft, or the current swift. In soft soils, the bed of the stream, below the lower edge of the down-stream apron, may be thickly covered with rubble for a distance of 10 to 20 feet, the rubble stone being rammed into the bed of the stream flush with the surface of the apron. A flat floor may be used when the bed of the stream is fairly hard and compact. If the ground is soft and yielding, and it is necessary to spread out the foundation bed area, so as to lessen the intensity of pressure per square foot, then across the waterway, between the abutments, there should be built an inverted arch supported on footing courses, and this inverted arch may be extended between the splayed retaining walls.

If the bridge or culvert has to sustain a heavy load (of earthen bank, etc.) and there is reason to fear a settlement of the abutments, accompanied by a squeezing up of the soil of the foundation bed into the waterway, the inverted arch flooring should be built.

§ 185 **CULVERTS** —Openings for the passage of water must be constructed through an embankment, carrying a road across the natural line of drainage of the country and therefore not only streams, but also the lowest points of depressions must be amply provided with a through waterway, sufficient to prevent any accumulation of water above the embankment

For permanent work these openings are built in brickwork, stonework or concrete, and are termed *culverts* they are of smaller span, and sectional area of opening than bridges, and often carry above them the greater part of the height of the embankment in such cases they must be built of sufficient strength to withstand the crushing pressure of the earth

For work of a more or less temporary nature, or where brickwork or stonework is not available, timber culverts may be constructed which will last for several years, and where good workmen are procurable, culverts carrying only a light weight may be built in dry rubble Figures 113 and 114 show two sections of culverts built in mortarless rubble

Where the current of water through the culvert is likely to be rapid, it is advisable to use mortar made with good hydraulic lime. If the culvert carries a light load, and the foundation bed of the side walls is in firm compact soil, not liable to be

FIG 113

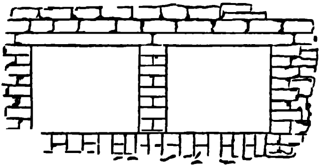


FIG 114

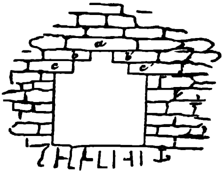


Figure 113 is an elevation of a flat-topped culvert with two openings, the bottom of the culvert is paved with brick set on edge

Figure 114 is an elevation of a culvert made of dry rubble with a corbelled top , the ends of the top stone a should project beyond the outer end of c *and* c'.

squeezed upwards into the opening; the floor of the waterway may be paved with flat stones where the current is slow, and with rectangular stones set on edge in mortar where there is a more rapid flow of water. When the pressure on the culvert is great, and the foundation bed is likely to yield laterally, an inverted arch in hydraulic mortar, or cement should be built between the side walls; just as in the similar case of a bridge erected on soft soil foundations (see § 184, page 244).

The inverted arch must be built resting on solid rigid foundation courses of masonry or concrete. Figure 115 shows an arch and invert of cut-stone, which should always be built in mortar.

FIG. 115

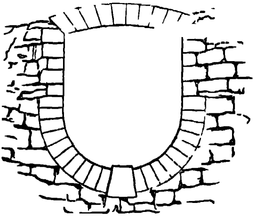


Figure 115 is an elevation of a culvert with an arched top and an inverted arched bottom.

The side walls may be of rough rubble, well-fitted and cemented together.

Where the volume of water is small, glazed earthenware socketted pipes of 12 inches bore and upwards, may be used, and in some cases, zinc-coated corrugated iron sheets have been bent into a hollow cylinder, rivetted up and used as pipes.

§ 186. Timber culverts, if the area of the passage is small can be built of the outside slabs sawn off squared logs; these slabs are fitted together as shown in figure 116, and are nailed with zinc-coated nails, or simply trenailed.

FIG. 116

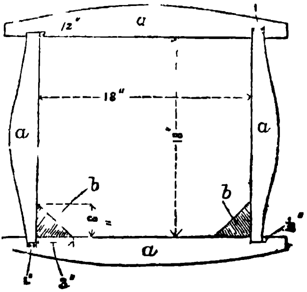


Figure 116 is an end-elevation of a small culvert made of slabs sawn off squared logs, either nailed together with zinc-coated nails or fastened together by trenails a a *are the slabs,* b b *the triangular-shaped fillets which check leakage (Scale 1 $\frac{1}{18}$)*

The triangular fillets nailed in the lower angles check leakage from the culverts, they are sometimes bedded in stiff plastic clay These culverts or trunking are made in convenient lengths, say of 12 to 14 feet, and when two lengths are to be joined, the simplest plan is to form a trimmed but-joint housed in a short length, say 2 feet of larger trunking of sufficient area to admit the two square trimmed abutting ends, and the joint can be made practically water-tight with a plastic clay lining to the outer trunking.

A larger timber culvert made of roughly squared logs, or slabs on two opposite sides, or on three sides, is shown in Figs. 117 and 118. The floor of the culvert is paved with rectangular stones on edge set in a framework of timber logs.

§ **187.** The actual size of a culvert depends upon the waterway to be provided for the natural drainage of the country. Culverts are seldom made of large span, or height of passage, unless provision has to made for an unusually rapid accumula-

FIG. 117

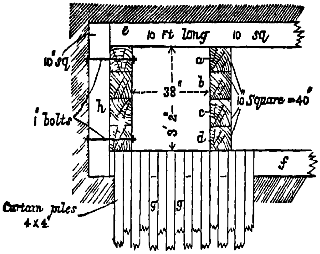


FIG 118

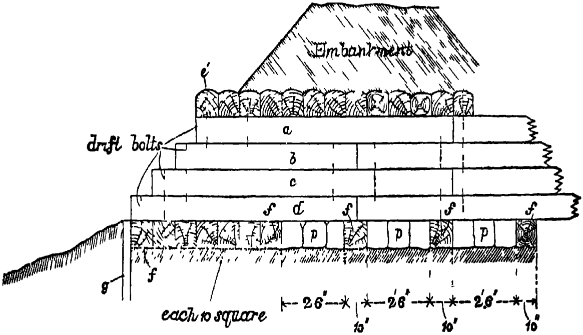


Figure 117 is a part end elevation, and figure 118 part longitudinal section of a timber log culvert used on the Canadian Pacific Railway The sides of the culvert are made of logs 10 inches square in section, a and c are 12½ feet long, b *and* d *8½ feet long,* d *is notched 1 inch deep into the floor logs These logs are drift bolted together through two logs and into a third The top of the culvert is formed of roughly squared logs (10" × 10") notched 1 inch on to the side and partition walls Uprights* h *are placed at intervals of 10 feet along the length of the culvert and fastened with 1 inch bolts to the logs* a *and* d *The floor is made of cross logs* f, f *placed at intervals of 2½ feet (except near the end of the culvert, which is formed of logs placed close together) and the spaces between are filled in with stone paving* p, p *The dotted lines in figure 118 passing through the logs a, b, c, and d, are drift bolts (Scale $\frac{1}{48}$) From* "Engineering," *published 13th December, 1895.*

tion of storm water, causing sudden high floods in streams In general if a large area of waterway has to be provided to carry off ordinary shallow flood water it is better and cheaper to make two or more small culverts side by side

The following table, showing the dimensions of culverts in Railway embankments taken from Molesworth s Pocket Book of Engineering Formulæ[1], may be of use in deciding upon the thickness of the arches and side walls of culverts used in road embankments As road carrying culverts are not subjected to the vibrations due to rapidly moving loads as on railways the dimensions in the table might be diminished by one-eighth to one-twelfth but in brickwork, dimensions are generally modified to the nearest half brick measurement, and, consequently, in these small culverts the tabular sizes are observed —

Nature of material used		t yard of m or br kwo k n ard of cu ert
Rubble masonry with hammer dressed arches	Flat top { 1 2	

SECTION VIII—PLANS AND ESTIMATES

§ 188. The plans and estimates for a bridge should be prepared in an exactly similar manner to those required for a building, and the instructions given in Volume I, Part II, Section XI, pages 280 *et seq*, should be followed

The estimate should begin with a report showing the necessity for the bridge, and the reasons for the selection of the design chosen. The drawings necessary to show the general design, and the details of the different parts of the structure should be submitted, as well as such working drawings as may be considered necessary.

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[1] 21st Edition page 108.

The calculations necessary for the determination of the dimensions of the different parts of important bridges should be given, but these are not usually necessary in the case of simple bridges of a small span.

A specification describing, in detail, the character of the work, the materials to be used, and the method of construction to be followed, should also be prepared. The quantities of materials required should be carefully taken out, the details of all the different sizes of scantings, etc , being shown separately. An abstract of the cost of the work should also be submitted.

PART IV.—BRIDGES.

APPENDIX I.

Table to show the values of the natural trigonometrical ratios of angles from 0°—90° correctly to three places of decimals (adopted from Molesworth's Pocket-book of Engineering Formulæ).

Angle in degrees.	Sine	Coversine	Cosecant	Tangent	Cotangent.	Secant	Versine.	Cosine.	
0	000	1 000	Infinite	·000	Infinite	1 000	000	1 000	90
1	·017	·983	57 299	·017	57 290	1 000	000	1 000	89
2	035	·965	28 654	·035	28 636	1 001	001	999	88
3	·052	948	19 107	·052	19 081	1 001	001	999	87
4	·070	·930	14 336	·070	14 301	1 002	002	·998	86
5	087	·913	11 474	·087	11·430	1·004	·004	996	85
6	·105	·895	9 567	·105	9 514	1 006	005	·995	84
7	·122	·878	8 205	·123	8 144	1 008	007	993	83
8	·139	·861	7 185	·141	7·115	1 010	010	·990	82
9	·156	·844	6 392	·158	6 314	1 012	012	988	81
10	·174	·826	5 759	·176	5 671	1 015	·015	·985	80
11	·191	·809	5 241	·194	5 145	1 019	·018	982	79
12	·208	·792	4 810	·213	4 705	1 022	·022	·978	78
13	·225	775	4 445	·231	4·331	1·026	026	·974	77
14	·242	·758	4 134	·249	4·011	1·031	030	·970	76
15	·259	·741	3 864	·268	3 732	1·035	034	·966	75
16	·276	·724	3·628	·287	3 487	1·040	·039	·961	74
17	·292	·708	3 420	·306	3 271	1·046	·044	·956	73
18	309	691	3 236	·325	3 078	1·051	·049	·951	72
19	·326	·674	3·072	·344	2·904	1 058	·055	·946	71
20	·342	·658	2 924	·364	2 747	1·064	·060	·940	70
21	·358	·642	2 790	·384	2·605	1 071	066	·934	69
	Cosine.	Versine.	Secant.	Cotangent.	Tangent	Cosecant	Coversine	Sine.	Angle in degrees.

Angle in degrees.	Sine.	Coversine.	Cosecant.	Tangent.	Cotangent.	Secant.	Versine.	Cosine.	
22	·375	·625	2·669	·404	2·475	1·079	·073	·927	68
23	·391	·609	2·559	·424	2·356	1·086	·079	·920	67
24	·407	·593	2·459	·445	2·246	1·095	·086	·914	66
25	·423	·577	2·366	·466	2·144	1·103	·094	·906	65
26	·438	·562	2·281	·488	2·050	1·113	101	·899	64
27	·454	·546	2·203	·510	1·963	1·122	·109	891	63
28	·469	·531	2·130	·532	1·881	1·133	·117	883	62
29	·485	·515	2·063	·554	1·804	1·143	·125	875	61
30	·500	·500	2·000	·577	1·732	1·155	·134	·866	60
31	·515	·485	1·942	·601	1·664	1·167	·143	·857	59
32	·530	·470	1·887	·625	1·600	1·179	152	·848	58
33	·545	·455	1·835	·649	1·540	1·192	·161	·839	57
34	·559	441	1·788	·675	1·483	1·206	·171	829	56
35	·574	·420	1·743	·700	1·428	1·221	·181	819	55
36	·588	·412	1·701	·727	1·376	1·236	·191	·809	54
37	·602	·398	1·662	·754	1·327	1·252	·201	·799	53
38	·616	384	1·624	·781	1·280	1·269	·212	788	52
39	·629	·371	1·589	·810	1·235	1·287	·223	·777	51
40	·643	·357	1·556	·839	1·192	1·305	·234	766	50
41	·656	·344	1·524	·869	1·150	1·325	·245	755	49
42	·669	·331	1·494	·900	1·111	1·346	·257	·743	48
43	·682	·318	1·466	·933	1·072	1·367	·269	·731	47
44	695	·305	1·440	·966	1·035	1·390	·281	·719	46
45	·707	·293	1·414	1·000	1·000	1·414	293	·707	45
	Cosine.	Versine.	Secant.	Cotangent	Tangent	Cosecant.	Coversine.	Sine.	Angle in degrees

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